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PROJECT FIRES, VOLUME 2: PROTECTIVE ENSEMBLE PERFORMANCE STANDARDS, PHASE 1B

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PREFACE

The Firefighters' Integrated Response Equipment System (FIRES) program was conducted by the Advanced Development Department of the Grumman Aerospace Corporation, under a contract jointly sponsored by the National Aeronautics and Space Administration (NASA), George C. Marshall Space Flight Center, and the United States Fire Administration (USFA). The program consists of three phases. Phase 1A led to the preliminary design of a prototype system. Phase 1B, the subject of this report, consists of prototype development, fabrication, and laboratory testing. Phase 2 will proceed through field testing and evaluation of the prototypes, resulting in an economical, fully-acceptable ensemble and finalized specification.

Project FIRES is a systematic approach toward the development of improved protection for structural firefighters. The system protects against such hazards as heat, flame, smoke, toxic fumes, moisture, impact, penetration and electricity. It also affords improved firefighter performance through increased maneuverability, lighter burdens, and improved human engineering designs.

This report is presented in four volumes as follows:

- Volume 1 - Program Overview and Summary
- Volume 2 - Protective Ensemble Performance Standards (PEPS) "Goals for Firefighter Protection"
- Volume 3 - Prototype Protective Ensemble Design Procurement Specification Report
- Volume 4 - Prototype Protective Ensemble Qualification Test Report

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ABSTRACT

Title: Project FIRES Phase 1B Final Report

Author: Fred J. Abeles

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(Body) In Phase 1A overall performance requirements and evaluation methods for firefighters protective equipment were established and published as the Protective Ensemble Performance Standards (PEPS).

Current firefighters protective equipment was tested and evaluated against the PEPS requirements, and the preliminary design of a prototype protective ensemble was performed.

In Phase 1B the design of the prototype protective ensemble was finalized. Prototype ensembles were fabricated and then subjected to a series of qualification tests which were based upon the PEPS requirements.

Engineering drawings and purchase specifications were prepared for the new protective ensemble.

Section 1

SUMMARY

This report presents the performance goals needed for the development of a structural firefighter's protective ensemble. Consisting of five integrated systems, the protective ensemble provides body protection, breathing gas, cooling, illumination, and a communications capability. Defining the performance requirements and the associated test methods (for their evaluation), the standards provide the foundation for the development of each of the systems comprising the Protective Ensemble.

Section 2

INTRODUCTION AND OBJECTIVES

This document presents the standards necessary for the development of a structural firefighters' protective ensemble. It is not intended to be used in its present form as a procurement document but as a guide for needed improvements to be used by designers and manufacturers. The goals presented herein are not based upon current equipment capabilities, but reflect requirements based upon both a realistic assessment of firefighter needs and the ability of improved technology to meet these goals.

Prepared over a thirty-three-month period under a jointly funded NASA and USFA study contract for the design of a firefighters' protective ensemble, the standards represent the concerted effort of many organizations. Included among these are the Grumman Aerospace Corporation, the contracting agencies, the NASA and the USFA, and the URC, a User Requirements Committee representing firefighters, fire chiefs, municipal officials, and public safety officers throughout the country.

The standards presented herein consist of the performance requirements and evaluation methods[1] that will be used for the development of a structural firefighters' prototype ensemble. This will ultimately serve as a forerunner of equipment to be made for the firefighting community.

The performance requirements presented are the end result of an effort to identify and quantify the actual hazards and environments typically encountered by structural firefighters. Complementing these are the evaluation requirements, or test methods, required for substantiating the capability of equipment to satisfy same. Both the performance and evaluation requirements are necessary steps in the evolution of a structural firefighters' protective ensemble.

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1 As of this writing evaluation methods have only been developed for the five subsystems comprising the Protective Garment System. Methods for the remaining systems, i.e., communications, lighting, etc., are not currently planned to be developed during the Project FIRES Program.

Section 3

SYSTEMS CONSIDERATIONS

The Protective Ensemble is defined as the integrated elements of the firefighters' personal protection system. The elements included in the Protective Ensemble are a Protective Garment System for body protection, a Self-Contained Breathing System and a Personal Cooling System for satisfying metabolic requirements, and Lighting and Communications Systems for enhancing visibility and communications at the fireground. These are protection items which are either worn or carried by the firefighter in responding to structural fires. This emphasis specifically excludes the specialized protective gear such as used for wild land, aircraft, or oil fires.

Prior to the formulation of performance requirements and test methods for the ensemble, the following major rationale necessary in establishing and satisfying these requirements were considered.

- Systems Integration - This term signifies two major considerations in the development of the requirements for the Protective Ensemble. The first of these is the close scrutiny of the firefighter's operating environment and duties to develop a set of standards for the Protective Ensemble based on the anticipated hazards faced in tasks performed by a firefighter. In fact, the definition and quantification of most requirements specified herein are based upon actual firefighter observations and experiences supplemented, when available, by field studies (both past and on-going). The second consideration in the development of the requirements is that of operational compatibility. Though the many functional elements that comprise the Protective Ensemble may be studied individually, systems integration will insure the operational compatibility between these elements. For example, systems integration will insure that the breathing apparatus is operationally compatible with the head protector and does not interfere with donning, or use at the fireground or loss of protection. In addition, wherever feasible, multiple functions should be combined into a single piece of equipment. For example, a safety harness could be combined with the torso/limbs protection subsystem; a communications device could be combined with the head/ear protection subsystems, etc.

- Commonality - It is currently the practice of many fire departments to provide similar if not identical personal protection equipment to all firefighters regardless of the differences between their tasks (truck company/engine company), the locale (urban, rural, suburban), the structure (highrise/frame) and the climate (summer/winter). It is highly probable that the requirements described in this document could in some cases dictate the need for variations in equipment based on either the climate or occupational needs. Therefore, in satisfying these needs, consideration will be given to both the feasibility of using variations in the equipment, and providing user options, as well as using one standard design for all.

- Infrequent Occurrences - Throughout a firefighter's career, situations or events occur which cause personal inconvenience or discomfort without causing an injury. Since these events are not encountered regularly and since protection against the event or situation can cause an excessive performance or weight penalty provision for such needs may not be provided. Protection against infrequent occurrences which result in injury will be incorporated into the protection criteria. Because of the massive design penalty, such rare events as building collapse and explosion will not be considered.

- Use of Existing Standards - As part of the performance requirement and test method development effort, existing standards and requirements were reviewed and their applicability assessed. Major standards examined include the National Fire Protection Association (NFPA), the Occupational Safety and Health Administration (OSHA), the American National Standards Institute (ANSI) standards; others examined are listed in the references. Those portions of the standards judged appropriate were incorporated into this document and are referenced. In those cases where existing standards were found lacking or non-existent, new requirements and test methods have been generated based upon field observations and best engineering judgement.

3.1 OCCUPATIONAL

The objective of the Protective Ensemble is to afford the firefighter protection so that he can function most efficiently and safely during the working tour. The working tour for a paid department member starts when the firefighter enters the firehouse and continues through the time he/she leaves the firehouse in street clothes. Volunteer and paid-on-call members of the fire services may, however, respond from a station in some cases while in others respond directly to the scene. For these firefighters the working tour starts with the response in accordance with departmental procedures.

3.1 OCCUPATIONAL (Contd)

Because the volunteer cannot be counted upon to be wearing clothing with any significant protective qualities at the time of "call" the volunteer's Protective Ensemble must not be dependent upon underwear or street clothes to satisfy the PEPS. On the other hand, the paid firefighter can be made to wear a specially designed set of underwear and station uniform with good protective qualities and another version of the Protective Ensemble can be designed to include these items in satisfying the PEPS requirements.

During the working tour, the firefighter is exposed to several different environments. These include the environment or conditions in the firehouse, conditions associated with responding and returning, and conditions at the fire ground. In the following paragraphs these conditions and how they relate to the design of the Protective Ensemble will be identified.

Fire Station - The fire station serves as a combination office, dormitory, garage, kitchen, machine shop, recreation room, study room and gymnasium. Temperatures can range from sweltering in the summer to overheated and dry in the winter. Therefore, the Protective Ensemble, or at least the parts worn in the firehouse, should be capable of providing the firefighter with a reasonable comfort level under various conditions.

In addition to the climatic needs, there are hazards associated with time spent in the fire station which the design of the Protective Ensemble must take into account. Examples of these are:

- In handling equipment, heavy objects or tools such as axes, haligans, power saws, etc., can fall on a firefighters feet
- The apparatus or fire station floor can become slippery because of various spills and result in falls
- Sliding down the fire pole can result in foot and ankle injuries

Responding and Returning - After an alarm comes into the fire station, the paid, uniformed firefighter is usually on the apparatus within 30 seconds, wearing full firefighting attire (except for breathing mask) and ready to respond. Therefore, the firefighter must be capable of adapting his station attire to firefighting attire within this time frame.

When getting on the apparatus the foot protector should have good traction since the apparatus' steps can be slippery. The Protective Ensemble must also be compatible with the apparatus allowing the man to sit in reasonable comfort or to ride on the back step securely and safely. Protection from other hazards, including objects thrown while

3.1 OCCUPATIONAL (Contd)

responding or returning, are not to be the responsibility of the system but must be considered a requirement of the apparatus.

Upon return from the alarm the firefighter is usually fatigued and wet with perspiration. The Protective Ensemble may also be soaked through from fire ground operations or rain. At this point, the firefighter would normally remove the firefighting attire, try drying the body, and possibly change undergarments. However, it is not unusual for another alarm to come in prior to this and he will have to respond once again in the same wet attire. This sequence can affect the health of the firefighters, particularly in cold weather.

Fire Ground - The prime consideration in the design of the Protective Ensemble is operation at the fire ground. It is here where the system should provide maximum protection enabling the firefighter to operate quickly, effectively and safely in a hazardous environment.

Fire ground operations can be considered in three phases, rescue, extinguishment (knock-down) and overhaul.

Rescue and Extinguishment (Knock Down) - This phase of the alarm starts with the firefighters getting off the apparatus at the fire ground. They are in full firefighting attire except for their breathing apparatus, which is put on immediately. The volunteer or paid-on-call member, on the otherhand, who arrives on the scene in an automobile wearing street or house clothing, must first don the turnout equipment and then the breathing apparatus.

Subsequent to equipment donning, the firefighters proceed to perform their jobs in a well coordinated teamlike manner. These tasks include raising ladders, making the entry (forceable), ventilation, examination, search, rescue, salvage, making hose hook-ups, selection, stretches, and deploying the water.

At the height of the fire the firefighters making the attack are faced with smoke, extreme heat, flames, zero visibility, falling debris, poor footing and many other unknown hazards that may surround them. However, wearing complete turnout attire and mask, the firefighters usually have a sense of security and comfort while making the attack. Somewhat oblivious to their own personal feelings, minor injuries, or how hard they are working, the firefighters are now part of a team with all members interdependent. Their prime function is to get the job done. When the fire has been extinguished, (knocked-down) the overhaul phase begins.

Overhaul - After the fire is brought under control, the firefighters must insure that every last ember is extinguished and debris and hazardous material must be removed from the

3.1 OCCUPATIONAL (Contd)

fire ground. During this process referred to as Overhaul, there is a tendency for firefighters to let up. Their main function successfully completed, they now become aware of their fatigue and their feelings of discomfort in the turnout attire. They may start shedding protective gear, removing their gloves, opening their collars, etc. It is at this stage that many firefighters are seriously injured in falls, by falling debris, by stepping on exposed nails and cutting edges, etc. Fatigue also leads to errors in judgment and degraded performance.

3.2 ENVIRONMENTAL

In the following paragraphs the environmental conditions that are prevalent at the fire ground are discussed as they relate to equipment and materials to be considered for the protective ensemble. The conditions described are due to and caused by the fire and fire ground operations. For a description of the thermal environment due to solar radiation and high and low ambient temperatures, see the section(s) discussing comfort.

Temperature - The temperature at the fire ground varies with fire conditions and the location. Field study data (Reference 1, 2) show that the firefighter generally operates in an environment ranging between 40°C (104°F) and 95°C (203°F), and on occasions may be exposed to temperatures as high as 250°C (482°F). The exposure time to these high temperatures is usually no more than a few minutes. On rare occasions the firefighter is subjected to the dreaded backdraft, when temperatures may reach 815°C (1500°F), however, the exposure time is usually limited to seconds. Therefore, any materials considered for the ensemble must be capable of satisfying these extreme conditions plus allow for a margin of safety.

Heat - There are three modes of heat transfer: conduction, convection, and radiation. Conduction, which is transfer by direct contact or through an intervening heat conduction medium, is usually the result of the firefighter coming in direct contact with a hot object, i.e., kneeling on a hot floor, picking up a hot object, etc. In these cases the contact temperature can be as high as 500°C (950°F) - 650°C (1202°F). Convection, which is heat transfer by a circulating gas or liquid medium, is usually the result of a firefighter coming in contact with circulating hot gases. In these situations the hot gas temperatures range from 40°C (104°F) - 815°C (1500°F) and the convective heat flux will vary both with air temperature and speed.[2] Radiant heat transfer is transfer by the emission of radiant energy

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[2] Per Reference 1 the convective heat flux can be calculated from the formula: $C/A = (8.6 \times 10^{-4}) V^{0.5} (Ta-35)$ where C/A = heat flux, watts/cm^2, V = air velocity, meters/sec, Ta = air temperature, ^{0}C

3.2 ENVIRONMENTAL (Contd)

waves from a hot body (or media) to a colder body (or media). The flames at the fireground are the greatest source of radiant energy, but other materials may radiate also. At fire-scenes where direct contact is not made with a hot object the heat load is comprised of both convective and radiative fractions. Studies (Ref. 1) show, however, that the contribution of convection to the total heat load is small when compared to thermal radiation.

Depending on the type of fire, the resultant heat flux may range from a relatively low level (.050 watt/cm^2) at the most common type structural fires, to an extremely high heat flux (up to 4.2 watts/cm^2) in a backdraft. The fire ground thermal environments in an involved structure may be characterized by four combinations of exposure time, temperature, and flux, as shown in the Table 3-1.

Table 3-1 - Thermal Environments

Class	Air Temp ^oC	Radiant Flux, Watts/cm^2	Exposure Time
1	40 (104^oF)	.050	30 MIN
2	95 (203^oF)	.100	15 MIN
3	250 (482^oF)	.175	5 MIN
4	815 (1500^oF)	4.2	10 SEC

Class 1 represents a common low intensity structural and a hot overhaul situation. Classes 2 and 3 are characteristic of an equally common "all hands" structural fire where considerable flame will be faced for 5 minutes, and less intense flame for 15 minutes after the initial attack. Class 4 is characteristic of a backdraft situation while a flashover falls between class 3 and class 4 conditions. The rationale for all subsystem/system design requirements will be based on the fact that Classes 1, 2 and 3 are commonly experienced, and should not result in any harm or pain to the firefighter. Also, the equipment shall not be degraded or visibly distorted by repeated exposure to these environments. The backdraft, Class 4, is considered a rarer occurrence and the primary consideration here is that the firefighter should not be injured. Although the equipment may be destroyed, the firefighter should not experience anything worse than temporary pain or minor injury. The threshold for skin damage is shown in Figure 3-1. Therefore, if these temperature-time limitations are not exceeded during the backdraft situation, the individual may experience pain but will not sustain any permanent skin damage. Thus materials considered for the ensemble must be capable of satisfying these conditions, plus allow a margin of safety.

3.2 ENVIRONMENTAL (Contd)

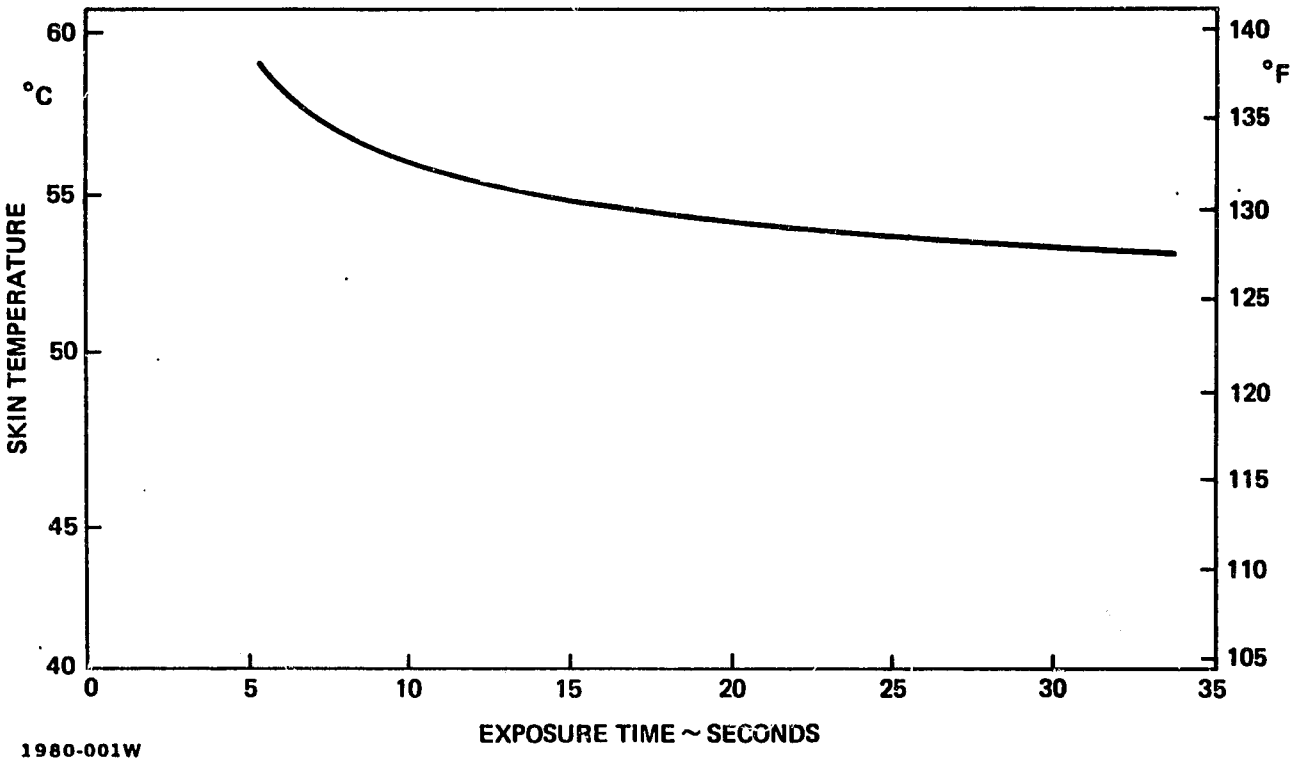

Figure 3-1. Exposure Conditions For Threshold Blister (Based on Data from Ref. 3)

Flame - The structural firefighter infrequently is in direct contact with flame in the normal course of his job. Whenever contact is made with flame, it is usually the result of a falling ember and only lasts a few seconds. The equipment, however, should be as flame resistant as possible to ensure that the protection is not degraded by repeated exposures.

Water - The primary problems associated with water at the fire scene arise when the firefighter gets wet, possibly soaked, all the way through his undergarments. The clothing becomes uncomfortable and the weight of the water absorbed contributes substantially to fatigue. Also, a wet garment in foul weather may result in illness or, possibly, in steam burns if the firefighter suddenly comes in contact with a heat source. Thus, in the selection of materials, the designer must be concerned with water repellency and water absorption. In addition, consideration must be also given to breathability or porosity, particularly in the torso area, or the firefighter will swelter (as is currently the case).

Smoke and Particulate Matter - Smoke and other toxic and irritating material require the firefighter to use adequate respiratory protection. Field analyses (Reference 4) show that the degree of toxicity is usually a combined result of the nature and concentration of the combustion products, the intensity of the heat and the duration of exposure. Because this information is not available to the firefighter a breathing apparatus must be used as a precautionary measure, sometimes even during the overhaul phase.

3.2 ENVIRONMENTAL (Contd)

Hazards - The Protective Ensemble must provide the maximum possible protection from the numerous hazards the firefighter encounters at the fire ground. In addition to environmental considerations, the following is a partial list of the typical hazards found at the fire ground from which the firefighter must be protected.

- Falling debris
- Certain structural failures
- Hot dripping paint/roofing materials
- Hot water
- Embers
- Jagged edges
- Broken glass
- Nails on floor
- Exposed live electric lines
- Ice on the ground/ladders
- Wet floors
- Poor footing
- Picking up hot objects
- Narrow hallways/confined areas

3.3 REQUIREMENTS

The requirements for the Protective Ensemble fall into five general categories. These are described below along with the specific criteria comprising each. The rationale for this subdivision is that each category covers a specific functional requirement of the firefighters' Protective Ensemble. In this manner identification of the specific criteria is more easily accomplished.

1) Protection - The criteria in this category cover the protective needs of the firefighter. These needs must be satisfied if the firefighter is to accomplish his/her duties without subjecting himself/herself to injury. Protective requirements are safety related needs. The criteria comprising this category are:

- Cut
- Electricity
- Flame
- Heat
- Impact
- Penetration (Puncture)
- Smoke/Toxic Contaminants

2) Performance - The criteria under this heading encompass those needs of the firefighter which must be fulfilled if the firefighter is to perform his/her duties at least as well as he/she is currently able to do. Unfulfilled, these needs affect not only job performance but safety. The criteria in this category are:

- Dexterity
- Grip
- Hearing
- Mobility
- Visibility

3) Comfort - The criteria in this group cover the comfort related needs of the firefighter. These requirements must be satisfied if the firefighter is to feel reasonably comfortable while tackling his/her job. These needs if not fulfilled also affect firefighter safety and job performance. The criteria constituting this category are:

- Fit
- Heat/Cold Insulation
- Retention
- Water penetration
- Weight

4) Service - The criteria in this category cover the service related aspects, or needs, of the firefighters equipment i.e., those concerned with equipment maintenance

3.3 REQUIREMENTS (Contd)

and life. Poor equipment service characteristics affect the safety and comfort of the firefighter as well as on-the-job performance. The criteria in this category cover:

- Dryability
- Durability
- Maintainability
- Reliability

5) Other - The criteria under this heading cover requirements which do not fit into any one of the other categories. Like the service requirements, however, they can impact the safety and comfort of the firefighter as well as job performance. Unlike the service criteria which are solely equipment requirements, the "other" criteria cover both firefighter and equipment requirements. The criteria covered under this heading are:

- Acceptance
- Compatibility
- Don/Doff
- Recognizability

In the following paragraphs requirements for each of all the above criteria are presented for the Protective Ensemble Systems and Subsystems.

REFERENCES FOR SECTION 3.0

1. "Thermal Environment During Structural Firefighting," R. F. Gempel and W. A. Burgess NFPCA Grant 76010 - 1977
Harvard School of Public Health

2. "A Firefighter's Integrated Life Protection System," Phase I Report, September 1974, Grumman Aerospace Corp.

3. Coletta, G. C., Arons, I. J., et al., "The Development of Criteria for Firefighters' Gloves," Arthur D. Little, Inc., Feb. 1976.

4. Fire Protection Handbook - 14th Ed. National Fire Protection Association (1976)

Section 4

PROTECTIVE ENSEMBLE

The function of the Protective Ensemble is to improve structural firefighter protection against hazards such as heat, flame, smoke, toxic fumes, moisture, impact, penetration and electricity, and to allow improved firefighter performance through increased maneuverability, lighter weight, improved human engineering design, and systems integration.

The elements included in the Protective Ensemble for structural firefighter are:

a) Protective Garment System

b) Self Contained Breathing System

c) Lighting System

d) Communication System

e) Personal Cooling System

A discussion of both the performance requirements and test methods is presented in the following sections for each of these. Except for heat, the requirements are first defined in commonly used terms i.e., terms familiar to a firefighter (a brick falling four stories). Later, in the test methods sections, the requirements are described in equivalent engineering terms to further define the performance needed and insure repeatability from test to test.

4.1 PROTECTIVE GARMENT SYSTEM

The Protective Garment System constitutes the major component of the firefighters' Protective Ensemble. Its function is to protect the firefighter against the environmental ravages of flame, heat, cold and water, while affording safety against such typical hazards as cuts, impact and puncture, encountered in structural firefighting.

The Protective Garment System as used by the firefighter today is comprised of a helmet for head protection, face shield for face/eye protection, turnout coat and pants and station uniform for torso/limb protection, gloves for hand and wrist protection, and boots for foot and ankle protection. As it currently exists the Protective Garment System does not meet many of the performance requirements specified herein. Equipment meeting all of these requirements has yet to be defined or designed. The systems engineering approach

4.1 PROTECTIVE GARMENT SYSTEM (Contd)

dictates that the items comprising a new subsystem may also be multifunctional or protect several areas of the body; current thinking and design approaches must be discarded for totally new concepts stressing integration of the protection functions for the various body areas. Since these functional groupings have yet to be identified appropriate equipment terminology (e.g., helmet, boot) does not exist. Therefore generic names, i.e., head protector, foot protector, have been used throughout this document. On this basis the Protective Garment System, as defined herein for the sake of convenience, consists of the following subsystems (Figure 4-1):

- Head/Ear Protection Subsystem (Sec. 4.1.1)
- Face/Eye Protection Subsystem (Sec. 4.1.2)
- Torso/Limbs Protection Subsystem (Sec. 4.1.3)
- Hand/Wrist Protection Subsystem (Sec. 4.1.4)
- Foot/Ankle Protection Subsystem (Sec. 4.1.5)

Table 4-1 presents the performance requirements in summary form. Several of these requirements, however, are identical and apply to all of the five subsystems. These are discussed below while the dissimilar requirements are discussed in subsequent sections along with test methods for all.

Flame - The various parts of the firefighters' body can contact flame in many instances and in a variety of ways. For example burning brands, flaming debris and flaming embers may shower down upon the head/ear, face/eye, or torso/limb protectors; or the hand/wrist, foot/ankle, and torso/limb protectors may be exposed to flame as the firefighter walks or crawls through, or handles flaming debris. To protect the firefighter under these various conditions the following flame resistance criterion is required for each of the five subsystems comprising the Protective Garment System.

- The subsystem shall not ignite, burn, char, melt or shrivel, or otherwise degrade when exposed to a 650°C (1200°F) flame for 5 seconds.

Electricity - In the wet environment that exists when the firefighter encounters an electrical hazard the situation is potentially deadly. Depending upon where the encounter takes place the electrical voltage the firefighter faces may be as little as 120 volts or as great as 2200 volts. At the maximum voltage normally encountered, the current flow through the body must be low enough so that no harm is caused. Thus, each of the five Protective Garment Subsystems must satisfy the following criterion.

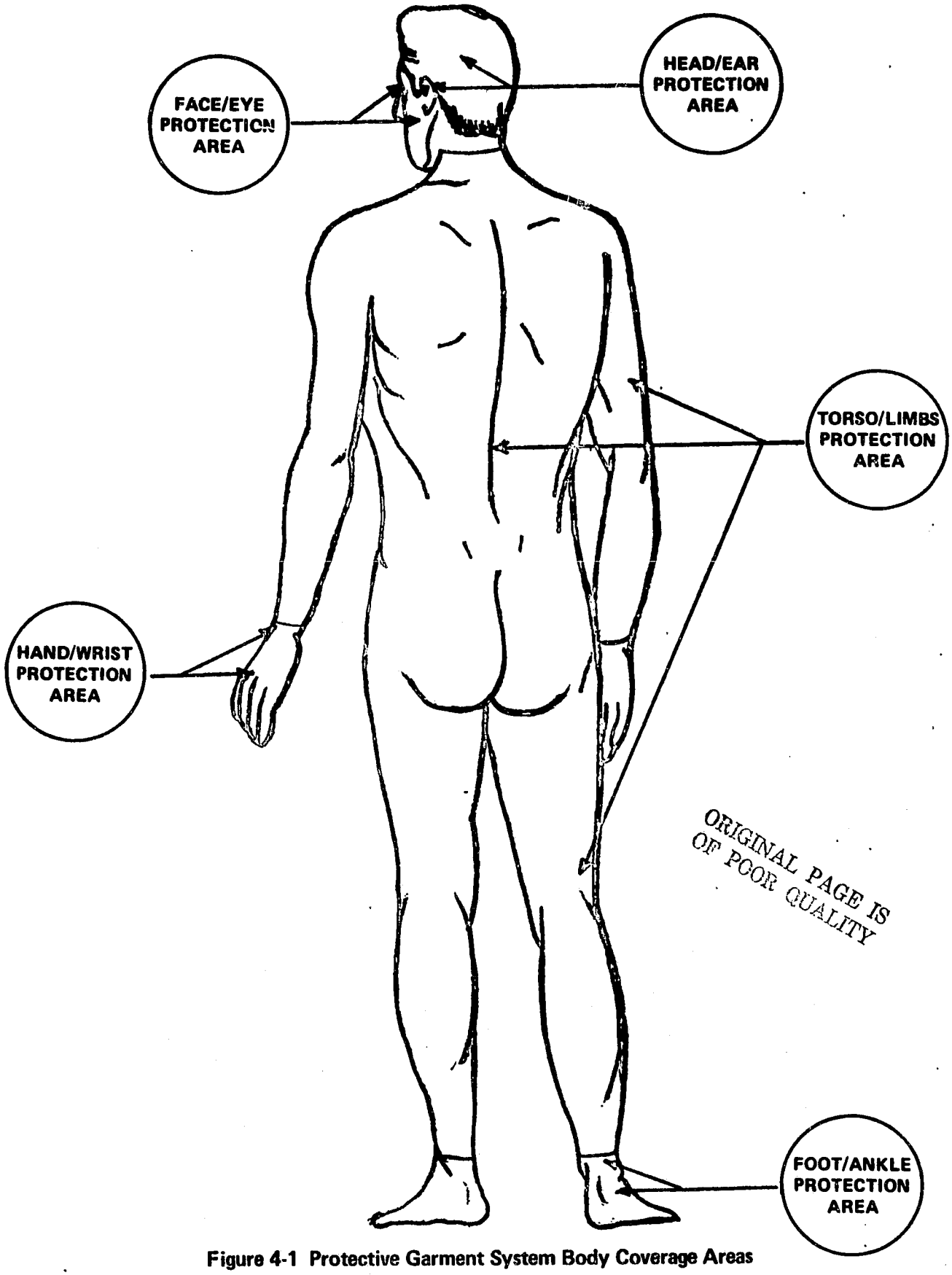

Figure 4-1 Protective Garment System Body Coverage Areas

Table 4-1 Summary of the Protective Ensemble Performance Standards (Sheet 1 of 6)

Protection Criteria

	Head/Ear	Face/Eye	Torso/Limbs	Hand/Wrist	Foot/Ankle
Impact	Limit head acceleration to Wayne State tolerances when hit by a brick falling 4 stories	Protector shall be serviceable after impact by brick	No bruises to firefighter's upper torso, elbows, and knees during falls	Protect back of hand against injury by falling slab of plaster	Protect toe from bruises caused by falling gas bottle or fire apparatus running over toe
Penetration	No injury from corner of brick falling 4 stories	No penetration by impacting nail	No puncture by nail	No penetration by nail	No nail penetration into sole of foot or side of arch
Cut	No cut damage by glass shards falling 4 stories	No cuts or scratches by sharp metal or grit	No cut damage by sharp metal edge	No cut through damage on palm side by sharp metal edge	No toe area cuts by saw blade; no instep cuts by falling glass; other areas not cut by metal edge
Flame	No ignition, burn, char, melt, etc. after exposure to flame	No ignition, burn, char, melt, etc., after exposure to flame	No ignition, burn, char, melt, etc. after exposure to flame	No ignition, burn, char, melt, etc. after exposure to flame	No ignition, burn char, melt, etc. after exposure to flame

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Table 4-1 Summary of the Protective Ensemble Performance Standards (Sheet 2 of 6)

Protection Criteria (contd)

	Head/Ear	Face/Eye	Torso/Limbs	Hand/Wrist	Foot/Ankle
Heat	• No distortion, meet all reqt's, & temps $\leq 113^{o}F$ in Class 1,2,3 No irreversible injury in Class 4	• No distortion, meet all reqt's, & temp $\leq 113^{o}F$ in Class 1,2,3 • Remain intact, & no irreversible injury in Class 4	• Meet all reqt's. & temps $\leq 113^{o}F$ in Class 1,2,3. • No irreversible injury in Class 4 • Inside temps $\leq 113^{o}F$ for conduction	• Meet all reqt's. & temps $\leq 113^{o}F$ in Class 1,2,3. • No irreversible injury in Class 4 • Inside temps $\leq 113^{o}F$ for conduction	• Meet all reqt's. & temps $\leq 113^{o}F$ in Class 1,2,3. • No irreversible injury in Class 4 4 • Inside temps $\leq 113^{o}F$ for conduction
Electricity	3 ma. max. leakage current at 2200 volts A.C.	3 ma. max. leakage current at 2200 volts A.C.	3 ma. max. leakage current at 2200 volts A.C.	3 ma. max. leakage current at 2200 volts A.C.	3 ma. max. leakage current at 2200 volts A.C.

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Table 4-1 Summary of the Protective Ensemble Performance Standards (Sheet 3 of 6)

Performance Criteria

	Head/Ear	Face/Eye	Torso/Limbs	Hand/Wrist	Foot/Ankle
Hearing	Reduction ≤ 10% allowed	N/A	N/A	N/A	N/A
Coverage & Visibility	N/A	Eyes, nose, cheeks & face to be covered; ANSI Z87.1 optical reqt's	N/A	N/A	N/A
Mobility or Dexterity	N/A	N/A	Task to be done with energy expend. ≤ 10% greater than with street clothes alone; range of motion to be ≥ 95% of that with no subsystem	Ability to rotate knobs, depress switches, & manipulate objects	Ability to climb stairs with energy expenditures ≤ 10% greater than with street shoes
Grip and/or Traction	N/A	N/A	N/A	Ability to swing ax and pull on a halyard (wet or dry)	Same traction as Vibram-soled boots on dry surfaces; icy or wet surface traction not to be less than 80% and 90%, respectively, of dry surface values

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Table 4-1 Summary of the Protective Ensemble Performance Standards (Sheet 4 of 6)

Comfort Criteria

Function	Head/Ear	Face/Eye	Torso/Limbs	Hand/Wrist	Foot/Ankle
Cold Insulation	Protect from cold at low temp. (-10°F) for 30 min.	N/A	Protect from cold at low temp. (-10°F) for 30 min.	Maintain a minimum of 59°F skin temp. at low air temps (-10°F)	Prevent discomfort in deep snow and maintain inner surface temp ≥ 59°F
Heat Insulation	Hot day energy expenditures ≤1% greater than when in street clothes alone	N/A	Hot day energy expenditures ≤10% greater than when in street clothes alone	N/A	N/A
Liquid Penetration	Deflect falling liquids and not be affected by hot liquids	N/A	Inside of garment shall not get wet by hot water and sweat shall be allowed to evaporate	Protector shall withstand 4 psi water pressure, absorb sweat, & prevent water penetration at hand/arm interface	No water penetration in deep water (8 in.) and no water entry at foot/leg interface
Weight	30 ounces	6 ounces	5.5 lbs for the 95th percentile	4 ounces per hand	4 lbs total for the 95th percentile
Fit	Must fit all head shapes and sizes	Sizes to provide equal protection to all	Available in numerical sizes	Available in 3 sizes	Available in full & half sizes and range of widths
Retention	Remain on head during falls & impact with objects	N/A	N/A	Retained on hand during active use	N/A

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(4/6)

Table 4-1 Summary of the Protective Ensemble Performance Standards (Sheet 5 of 6)

	Service Criteria				
	Head/Ear	Face/Eye	Torso/Limbs	Hand/Wrist	Foot/Ankle
Maintainability	Basic repairs in fire station	Basic repairs in fire station	Basic repairs in fire station	Basic repairs in fire station	Basic repairs except for soles & heels in fire station; use of standard tools, techniques for shop repairs
Reliability	Meet all performance requirements throughout service life	Meet all performance requirements throughout service life	Meet all performance requirements throughout service life	Meet all performance requirements throughout service life	Meet all performance requirements throughout service life
Durability	5 yrs service life	5 yrs service life except for lens which have 6 months	3 yrs service life	6 months service life	2 yrs service life
Don/Doff	Don in 5 seconds	Deployed in 2 seconds; stowed in 3 seconds	Don in 10 seconds	Don or doff within 5 seconds	Don within 8 seconds; rapid doffing
Dryability	After soaking, dryable within: -6 hrs at room temp. -1 hr in oven	N/A	After soaking, dryable within -6 hrs at room temp -1 hr in oven	After soaking, dryable within -3 hrs at room temp -20 min in oven	After soaking, dryable within -6 hrs at room temp. -1 hr in oven
Recognizability	Light in color and have retroreflective surfaces	N/A	Retroreflective surfaces	Retroreflective back surfaces	Retroreflective surfaces
Acceptance	Protector shall be acceptable and promote usage	Protector shall be acceptable and promote usage	Protector shall be acceptable and promote usage	Protector shall be acceptable and promote usage	Protector shall be acceptable and promote usage

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Table 4-1 Summary of the Protective Ensemble Performance Standards (Sheet 6 of 6)

Service Criteria (contd)

Function	Head/Ear	Face/Eye	Torso/Limbs	Hand/Wrist	Foot/Ankle
Compatibility	Compatible interfaces with Torso/limbs, Face/eye, Communication, Lighting & Breathing Systems.	Compatible interfaces with Head/ear and Comm. Systems; no interference with Breathing System	Compatible interfaces with all systems and subsystems; no exposed skin at wrists or ankles	Compatible interface with Torso/limbs subsystem and Lighting System; prevent entry of dirt & water into Hand/wrist area or Torso/limbs subsystem	Compatible interface with leg protector; watertight seal at interface
	No interference with deployment, storage or use of tools, lights, or communication systems	No interference with deployment, storage or use of tools, lights, or communication systems	No interference with deployment, storage or use of tools, lights, or communication systems	No interference with deployment, storage or use of tools, lights, or communication systems	No interference with deployment, storage or use of tools, lights, or communication systems

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4.1 PROTECTIVE GARMENT SYSTEM (Contd)

- The subsystem shall limit the current flow to less than 3 milliamperes when there is a 2200 volt AC electrical potential between the subsystems outer surface and the part of the body it is in contact with. This criterion shall be met with the outer surface of the subsystem either wet or dry.
- The stated protection shall be provided at room temperature as well as:
  a) immediately after the protection subsystem has been subjected to the Class 2 and 3 thermal environments described in Table 3-1
  b) after the subsystem has achieved an equilibrium temperature of -50°C (-58°F)

Weight - A design goal of approximately a 50% weight reduction in current Protective Ensemble System weight is both desirable and feasible. Current systems, which do not include a Personal Cooling System weigh approximately 28.0 kg (62 lb). Thus, as a goal the new system weight, less the Personal Cooling System, should be under 14.0 kg (31 lb). The projected new system weight including a Personal Cooling System is as follows:

	Current		Projected	
	kg	lb	kg	lb
Protective Garment System				
• Head/Ear	1.70	(3.75)	0.81	(1.9)
• Face/Eye	0.23	(0.5)	0.17	(0.375)
• Torso/Limbs	4.5	(10.0)	2.3	(5.0)
• Hand/Wrist	0.23	(0.5)	0.23	(0.5)
• Foot/Ankle	3.40	(7.5)	1.8	(4.0)
Self Contained Breathing System	15.0	(33.0)	7.0	(15.5)
Lighting System	1.1	(2.5)	0.68	(1.5)
Communication System	1.8	(4.0)	0.45	(1.0)
Personal Cooling System	-	-	2.3	(5.0)
System Total	28.0	(61.75)	15.74	(34.78)

4.1 PROTECTIVE GARMENT SYSTEM (Contd)

On this basis the following requirement for the Protective Ensemble is established:

- As a design goal the weight of the Protective Ensemble shall not exceed 16.4 kg (36 lb).

Maintainability - To a large degree the maintenance requirements of the five subsystems are identical. Only the foot/ankle protector has some different requirements. For the most part, however, the maintenance on the subsystems will consist of cleaning, repairing cuts, tears and abrasive wear, and, possibly, waterproofing. To accomplish this the following requirement is established.

- The subsystems maintenance shall be capable of being performed by firefighters at the fire station. If any process used requires curing, such as for adhesives or waterproofing, the curing shall be completely effective after 6 hours at room temperature.

Insofar as the foot/ankle protection subsystem is concerned the following additional criterion applies.

- In station maintenance of the foot/ankle protector may be limited to areas other than the soles and heels. If a shoe repair shop is required for repair, only the standard tools and techniques used in such a shop shall be required and the repair shall be consistent with present practice on conventional boots.

Reliability - The firefighting and storage environments will, in time, age the Protective Garment Subsystems. However, the firefighter must be assured of reliable performance every time any of the subsystems is worn. Toward this end each of the subsystems must satisfy the following criterion.

- The subsystem shall, at a minimum, satisfy all of the protection, performance, comfort, and service criteria pertinent to it for a length of time equal to its service life.

Durability - In the interest of economy the firefighters equipment must have a reasonable service life, one which considers both the storage and operating environments that the equipment will be subjected to. The storage environment may be that of a fire station, fire apparatus, or even the inside of an automobile. In these instances the equipment may be exposed to vehicle exhaust gases, vehicle maintenance fluids (e.g., battery acids, brake fluids, gasoline, etc.), fire station cleaning compounds, and even possibly to household cleaning and laundering agents. Any of these will take their toll on the service life of the

4.1 PROTECTIVE GARMENT SYSTEM (Contd)

equipment although the degradation will be small in comparison to the degradation anticipated in an operating, or usage, environment. In the usage environment, which can be internal or external to the fireground, the equipment is exposed to the potentially degradatory effects of both the natural elements (e.g. sun and rain) and the by-products of the fire namely, heat, corrosive gases, flame, etc. It's anticipated that service life degradation will be most pronounced in the usage environment. The total effect on service life must be considered, however, and for this reason the service seen at a busy metropolitan fire company (a fire company at which each firefighter responds to approximately 700 alarms per year) is given as the basis for the following requirement:

- The subsystems shall be durable enough to provide service (as defined in Reliability, above) with a busy metropolitan fire company for the time period minimums shown:
  a) Head/Ear protector - 5 years
  b) Face/Eye protector (excluding replaceable lens) - 5 years
     Face/Eye protector lens - 6 months
  c) Torso/Limbs protector - 3 years
  d) Hand/Wrist protector - 6 months
  e) Foot/Ankle protector - 2 years

Acceptance - In an effort to induce the firefighter to wear all of the required Protective Garment Subsystems and thereby reduce the possibility of some items not being used, or misused, the subsystems need to be designed to gain widespread acceptance by their users. Towards this end the following requirement is necessary:

- The overall characteristics of each of the subsystems shall be acceptable to the firefighter and shall promote a desire to use the protection subsystem.

4.1.1 Head/Ear Protection Subsystem

The head/ear protection subsystem must protect the firefighters' head and ears from impact and penetration of flying and falling objects, as well as from heat, flame, electrical shock and burns. The subsystem shall also divert liquids and debris from the face and neck. In providing this protection, the system must not restrict the firefighters' hearing, and the neck must be afforded mobility so as to allow easy performance of tasks. A range of sizes, or an adjustment, must be provided to insure proper fit, as well as means to insure that the subsystem is kept on the head.

4.1.1 Head/Ear Protection Subsystem (Contd)

4.1.1.1 Requirements

Protection Criteria

Impact - "Worst-case" examples of impact hazards that must be protected against are: a) a section of plaster construction ceiling falling 3 m (9.8 ft), and b) a brick falling off a 4-story building (approximately 12 m (39 ft). Based on these events, the following impact protection criteria shall apply:

- The head/ear protection subsystem shall limit the acceleration of the head to within the safe range of the Wayne State University Tolerance Standards (see Figure 4-2) when impacted with 21 kg-m (152 ft-lb) on the top (apex), front, back and sides of the head.
- The above protection shall be provided at room temperature as well as:
  1) immediately after the subsystem has been subjected to the Class 2 heat environment and the Class 3 heat environment described in Table 3-1.
  2) after the subsystem has achieved an equilibrium temperature of -50°C (-58°F).
  3) after the subsystem has been wetted by 82°C (180°F) water for 5 minutes.

Penetration - The head/ear protection subsystem may be struck by falling debris such as the corners and edges of bricks and other masonry, and also by the points of nails that might be protruding from a falling board. In addition, puncture damage may be inflicted by a fall on the same level if the subsystem strikes an edge or corner of a runningboard of an apparatus, a step, or a counter top. To provide safety and durability under these circumstances, the following criteria shall apply.

- The head/ear protection subsystem shall prevent any injury resulting from: the corner of a brick striking the top of the subsystem after freefalling 12 m (39 ft).
- The above protection shall be evaluated by room temperature as well as:
  a) immediately after the subsystem has been subjected to the Class 2 heat environment and the Class 3 heat environment described in Table 3-1 on Page 2/3-6.
  b) after the subsystem has achieved an equilibrium temperature of -58°C (-58°F).

4.1.1 Head/Ear Protection Subsystem (Contd)

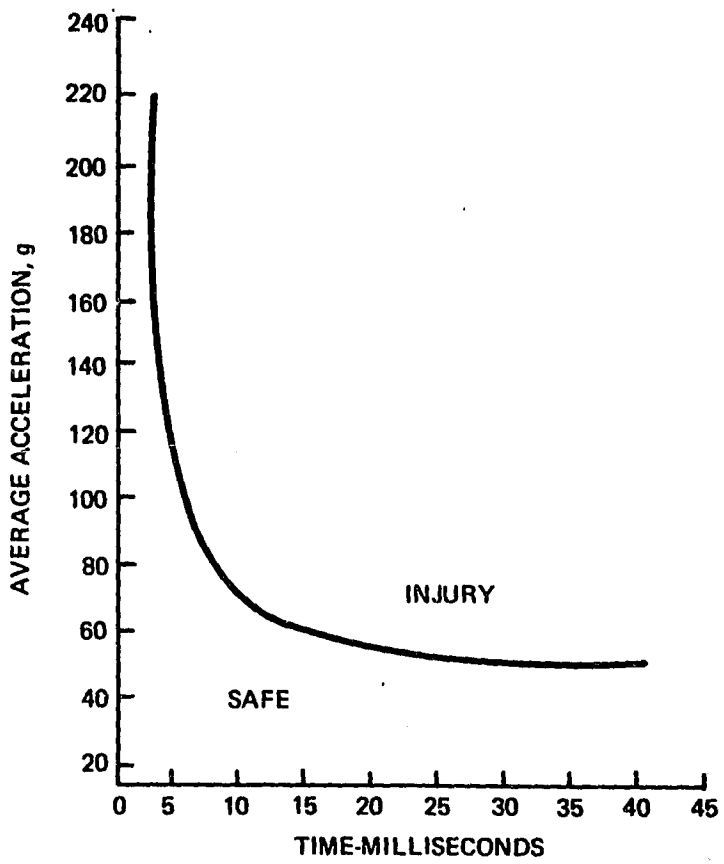

Figure 4-2 Wayne State University Cerebral Concussion Tolerance Curve

4.1.1 Head/Ear Protection Subsystem (Contd)

Cut - Cut protection is required to insure the integrity of the outer surface of the head protector when meeting sharp objects such as falling glass or other debris. While not likely to penetrate the subsystem, this might cause surface damage and hence compromise the protective capabilities of the head protection equipment. To this end, the following criteria are established:

- The head/ear protection subsystem shall not be cut by shards of glass falling from a height of 12 m (39 ft)
- The above protection shall be provided at room temperature as well as:
  a) immediately after the subsystem has been subjected to the Class 2 and 3 heat environments described in Table 3-1.
  b) after the subsystem has achieved an equilibrium temperature of -50°C (-58°F).
  c) after the subsystem has been wetted by 82°C (180°F) water for 5 minutes.

Flame - The requirements are covered on Page 2/4-2.

Heat - Heat strikes the firefighters' head and ears primarily through radiation, although conduction via hot air plays a role. The characteristic fire scene thermal environments encountered by the firefighter are given in Table 3-1. Based on these considerations, the following design criteria are required for heat protection:

- The head/ear protection subsystem shall withstand each of the thermal environments of Classes 1, 2, and 3 without any visible distortion and subsequently meet all other requirements without any of the inner surface of the subsystem that contacts the head or ears reaching 45°C (113°F), the pain threshold.
- When subjected to the Class 4 environment the inner surface of the head/ear protection subsystem that contacts the head or ears shall not exceed the Figure 3-1 temperature-time limitations.

4.1.1 Head/Ear Protection Subsystem (Contd)

- After having been wetted with 82°C (180°F) water at a rate 60 liters per minute (15.9 gallons per minute) for 10 minutes the subsystem shall withstand the thermal environments of Class 1, 2 and 3 without resulting in steam vapor temperatures on the inside of the protector that exceed 45°C (113°F). Under Class 4 conditions and after wetting with water as described above any steam vapor present in the inside of the protector shall not exceed the Figure 3-1 temperature-time limitations.

Electricity - These requirements are given on Page 2/4-2.

Performance Criteria

Hearing - Voice communication is critically important at the fire ground. Commands are transmitted orally between the company officer and the men, warnings may be shouted between firefighters, and the search and rescue squad must be able to hear the cries of any victims. It is thus important that the head/ear protection subsystem not cause an unacceptable compromise in hearing ability, as will be assured by the following requirement:

- The head/ear protection subsystem must not attenuate hearing more than 10%.

Comfort Criteria

Cold Insulation - To insure that the firefighter can work in all weather he must be as comfortable as possible at all times. Winter is considered the most severe environment for the head/ear protection subsystem; in extremely cold weather, cases of frostbitten ears are possible. This leads to the following cold insulation criterion:

- The head/ear protection subsystem shall incorporate a means of protection against extreme winter cold. When the subsystem is in place, protection against frostbite shall be provided when worn for 30 minutes in a -23°C (-9.4°F) atmosphere with a windchill factor of -50°C (-58°F).

4.1.1 Head/Ear Protection Subsystem (Contd)

Heat Insulation - The firefighter must be able to perform tasks in summer heat as well as winter cold. While summer temperatures and solar radiation do not lead to frostbite or other severe injuries, the combination of heat, humidity, solar radiation, and workload can result in high metabolic loads and sweat production rates. Under these conditions, a firefighter may experience heat exhaustion, and/or dehydration and/or cardiac distress. Thus, it is important that the stress imposed by the head/ear protector shall be minimized. This leads to the following criterion:

- When worn by a firefighter on a hot summer day (i.e., at 95°F, 80% relative humidity, wind velocity less than 5 mph, and a solar radiance of 0.1 watt/cm^2) the head/ear protector shall not increase the firefighters energy expenditure by more than one percent compared to the firefighter wearing street clothes alone.

Water and Other Liquid Penetration - Every working firefighter can be subjected to falling or splashing liquids. Hot and cold water may drip through ceilings or come from a discharging sprinkler head, broken pipe, or ruptured hose. Hot melted paint or tar may fall on the firefighter. The head/ear protection subsystem must guard against these hazards, and deflect these liquids. For this purpose, the following criteria shall be imposed:

- The head/ear protection subsystem shall be designed to deflect falling liquids
- It shall not be affected by: 82°C (180°F) water falling on it at a rate of 60 liters per minute (15.9 gallons per minute) from a sprinkler head from a height of 1.5 m (5 ft) for 10 minutes
- Water absorption shall be 0 kg (0 lb).

Weight - To assure comfort and minimize fatigue, the head/ear protection subsystem must be as light as possible. To this end, the following criterion is established:

- The head/ear protection subsystem shall weigh a maximum of 850 grams (30 ounces).

4.1.1 Head/Ear Protection Subsystem (Contd)

Fit - The head/ear protection subsystem worn by the firefighter must fit properly and be comfortable. It is axiomatic that unless the head/ear protection subsystem is properly in place it cannot protect the wearer. The subsystem must have the proper "feel" on the head; that is, the firefighter must have a physical awareness of the subsystem and psychological issurance that it will remain in place. To this end, the following criterion is required:

- A range of sizes, or an adjustment, shall be provided so that the head/ear protection subsystem will accommodate all sizes and shapes of firefighter's heads and a variety of hair styles and lengths.

Retention

- The head/ear protection subsystem shall not be the cause of injury and shall remain on the head if the firefighter:
  a) falls off the back step of an appratus as the vehicle turns a 90° corner at 40 kilometers per hour (25 mph) and he is thrown off in a centrifugal direction
  b) if a shower of roofing gravel hits the outermost edge of the brim from a height of 6 meters (19.7 ft)
- The retention system shall not cause injury when the brim is impacted by a 21 kg-m (152 ft-lb) impact load.
- The retention system shall not cause injury when the head protection subsystem becomes caught or stuck on/by an obstruction.

Service/Other Criteria

Maintainability - These requirements are given on Page 2/4-11.

Reliability - These requirements are given on Page 2/4-11.

Durability - These requirements are given on Page 2/4-11.

Donning

- The head/ear protection subsystem must be capable of being donned and ready for use in 5 seconds.

Recognizability - To aid in identification of firefighters particularly when visibility is impaired by smoke or darkness, the following requirements are necessary:

- The head/ear protection subsystem shall be light in color and/or provided with retroreflective surfaces to make it visible at distances up to 200 feet at night.

4.1.1 Head/Ear Protection Subsystem (Contd)

- Provision shall be made for color variations and for attaching badges and emblems denoting rank, task, organization, etc.

Dryability - There is a possibility that the inside of the firefighters head/ear protection subsystem will become wet with perspiration. For this reason, it must be capable of being dried out in a reasonable time, e.g., the normal time between shifts. Towards this end the following requirement is necessary:

- A head/ear protection subsystem that has been immersed in water for 5 seconds shall be capable of being dried (95% of the absorbed water removed) in either of the following ways:
  a) 6 hr of air drying at room temperature
  b) 1 hr in a 95°C (203°F) oven.

Acceptance - These requirements are given on Page 2/4-12.

Compatibility - To assure the effectiveness of the entire firefighters' ensemble, it is necessary that all the component items function well together. To this end, the following criteria are necessary:

- The head/ear protection subsystem shall incorporate a means to ensure that a compatible interface exists between it and,
  a) the torso protection subsystem (with particular attention given to the neck area)
  b) the face/eye protection subsystem
  c) the Communication System
  d) the Breathing System
  e) the Lighting System.

There shall be no interference when donning and doffing and there shall be no resulting gaps that would permit entry of debris or water.

4.1.1 Head/Ear Protection Subsystem (Contd)

4.1.1.2 Test Methods

Protection Criteria

Impact

"The head/ear protection subsystem shall limit the acceleration of the head to within the safe range of the Wayne State University Tolerance Standards when impacted with 21 Kg-m (152 ft-lb) on the top (apex), front, back and sides of the head."

"The above protection shall be provided at room temperature as well as:

(1) immediately after the helmet has been subjected to the Class 2 and 3 heat environments.

(2) After the helmet has reached an equilibrium temperature of -50°C (-58°F).

(3) After the helmet has been wetted by 82°C (180°F) water for 5 minutes."

The impact tests on the firefighters head protective subsystem will be performed in accordance with the procedure which has been prepared by the joint American National Standards Institute/National Fire Protection Association (ANSI/NFPA) Fire Fighter Head Protection Subcommittee. For the test where the helmet/headform assembly is dropped onto a rigid anvil, reference is made to "Model Performance Criteria for Structural Firefighters' Helmets" (Ref 1). The test utilizing an impact mass dropping on a helmet headform assembly, is referenced to the ANSI Z90.1 specification (Ref 5).

For impacts on the front, sides and back of the head protective subsystem the test procedures of the "Model Performance Requirements" will be used as recommended in the ANSI/NFPA standard.

The procedures referenced above will require modification in the areas of input energy and pre-test conditioning in order to conform to the specific protection criteria.

Puncture

"The head/ear protection subsystem shall prevent any injury resulting from the corner of a brick striking the top of the helmet after free-falling 12 m (39 ft)."

"The above protection shall be evaluated at room temperature as well as:

(a) immediately after the helmet has been subjected to the Class 2 and 3 heat environments.

4.1.1 Head/Ear Protection Subsystem (Contd)

(b) after the helmet has achieved an equilibrium temperature of -50°C (-58°F)

(c) after the helmet has been wetted by 82°C (180°F) water for 5 minutes".

This requirement will be conducted on a drop machine to which is attached the corner section (3 surface intersections at 90° to one another) of a striker mechanism. The drop mass, including the striker, will be initially accelerated from a convenient height so that it impacts the helmet at the apex. The impact momentum shall be adjusted to simulate a brick falling a distance of 2m (39 ft) with a 21 kg-m (512 ft-lb) impact energy.

The head protective device will be mounted on a rigid headform using the normal chinstrap attachment fittings. The apex of the headform shall contain a two inch diameter drilled recess, filled with modeling clay and shaped to maintain a continuous, smooth profile with the surface of the rigid headform. The headform shall be located under the drop mass so that the striker will contact the approximate center of the clay section, if the helmet were removed.

The rejection criteria will be any indication of the striker impression in the clay surface.

Cut

"The head/ear protection subsystem shall not be cut by shards of glass falling from the height of 12m (39 feet)".

"The above protection shall be provided at room temperature as well as

(a) immediately after the helmet has been subject to the Class 2 and 3 heat environments.

(b) after the helmet has achieved an equilibrium temperature of -50°C (-58°F).

(c) after the helmet has been wetted by 82°C (180°F) water for 5 minutes."

This test can be performed by a drop test machine with the impacting mass modified by the attachment of a triangular shard of glass. The drop mass shall be raised to an appropriate height to impact the helmet on its apex, when placed on a rigid headform mounted on the base of the machine. The failure criterion will be a rejction if the glass shard penetrates the helmet shell.

4.1.1 Head/Ear Protection Subsystem (Contd)

Flame

"The subsystem shall not ignite, burn, char, melt or shrivel, or otherwise degrade, when exposed to a 650°C (1200°F) flame for 5 seconds."

This requirement can be met through a flame impingement test where a commercially available natural gas nozzle is employed. The nozzle would be fed with natural gas and a 320% excess air mixture in order to achieve the required flame temperature. The nozzle will be hand held and the flame temperature checked with an appropriate thermocouple junction. The flame will be directed at the helmet shell and any other features, such as ear flaps and face shields. The flame will be directed at each surface at a 45 degree angle from the normal to that surface. Each surface shall be exposed for a 5 second period.

Heat Resistance

"The head/ear protection subsystem shall withstand radiated heat environments of Classes 1, 2, and 3 without any visible distortion and subsequently meet all requirements without any of the inner surface of the subsystem that contacts the head or ears reaching 45°C (113°F) (pain threshold). During testing, Class 1 shall be imposed separately, while Class 2 and 3 shall be run together with Class 2 first followed by Class 3."

"When subjected to the Class 4 environment the inner surface of the head/ear protection subsystem that contacts the head shall not exceed the Figure 3-1 temperature-time limitations."

"After having been showered with 82°C (180°F) water at a rate of 60 liters per minute (15.9 gallons per minute) for 10 minutes the subsystem shall withstand the thermal environments of Class 1, 2 and 3 without resulting in steam vapor temperatures on the inside of the protector that exceed 45°C (113°F). Under Class 4 conditions and after showering with water as described above any steam vapor present in the inside of the protector shall not exceed the Figure 3-1 temperature-time limitations."

Each helmet would be instrumented with thermocouple junctions attached to the inner surface of the helmets. Four locations are as follows:

(a) Apex
(b) Front
(c) Side
(d) Back

These temperatures would be continually recorded during the exposure periods.

4.1.1 Head/Ear Protection Subsystem (Contd)

The first criterion exposures can be performed in a manner similar to that detailed in method 505 of MIL-STD-810 for heat build up, with appropriate modifications to accommodate the desired air temperature, radiant flux and exposure times. During these exposures, a simulated headform would be used to mount the helmet with the normal attachment fittings. This would permit only typical airflow to take place within the helmet shell. The thermocouple would be insulated from this airflow in any case.

The second, third, and fourth criteria can be accomplished by an extension of the methods used above. The third and fourth criteria, however, require the helmets' outer surfaces to be showered with water at the stated conditions before being subjected to the various thermal environments.

During testing conditions would first have to be established in the chamber and then the helmet, mounted on the headform, together with the attached thermocouples would be momentarily placed into the chamber for the required exposure period.

Electricity

The subsystem shall limit the current flow to less than 3 milliamperes when there is a 2200 volt A C electrical potential between the subsystems outer surface and the part of the body it is in contact with. This criterion shall be met with the outer surface of the subsystem either wet or dry.

The stated protection shall be provided at room temperature as well as:

(a) immediately after the subsystem has been subjected to the Class 2 and 3 thermal environments described in Table I

(b) after the subsystem has achieved an equilibrium temperature of -50°C (-58°F).

This requirement can be evaluated by using the procedure described in Paragraph 2.6 "Electrical Insulation Test" of the Model Performance Criteria for Structural Firefighters Helmets." For the evaluation of a wet helmet it shall be wetted with 82°C (180°F) water for 5 minutes and shaken dry before being subjected to the test.

Performance Criterion

Hearing

"The head/ear protection subsystem must not attenuate hearing more than 10%."

This requirement can be met by monitoring the audiometric characteristics of a panel of six people in accordance with the equipment specified and procedures required by

4.1.1 Head/Ear Protection Subsystem (Contd)

ANSI Z24.22 titled "Measurement of the Real Ear Attenuation of Ear Protectors; Method for". The entire procedure would then be repeated with the helmet in position and the attenuation could then be determined.

Comfort Criteria

Cold Insulation

"The head/ear protection subsystem shall incorporate a means of protection against extreme winter cold. When the subsystem is in place, protection against frostbite shall be provided when worn for 15 minutes in a -23°C (-9.4°F) atmosphere with a windchill factor of -50°C (-58°F). The winter protector shall not compromise any of the performance requirements of this document".

This requirement can be met by mounting the helmet on a heated headform to which thermocouple junctions have been installed in the crown area and ear area. The helmet/headform assembly shall then be placed in an environmental cold temperature, air circulating chamber stabilized at -23°C (-9.4°F). The exposure period should be 15 minutes, during which time the thermocouple outputs would be continuously recorded.

Heat input to the helmet will simulate heat input to the normal head. The chamber air flow shall be adjusted to provide the required windchill factor.

The failure criterion would be any temperature recorded by the thermocouples which indicate a headform "skin" temperature below 15°C (59°F).

Heat Insulation

"When worn by a firefighter on a hot summer day (i.e., at 95°F, 80% relative humidity, wind velocity less than 5 mph, and a solar radiance of 0.1 watt/cm^2) the head/ear protector shall not increase the firefighters energy expenditure by more than one percent compared to the firefighter wearing street clothes alone."

For this evaluation an environmental chamber is required for performing the test procedure described in Reference 4. This procedure will be utilized on a test subject first clothed in street clothes alone, and then in street clothes with the protector. Energy expenditures with the protector worn shall not exceed those with street clothes alone by more than 1.0%. (For the purposes of this experiment street clothes consist of underwear, shirt, pants, socks, and low cut shoes).

2

4.1.1 Head/Ear Protection Subsystem (Contd)

Water and other Liquid Penetration

"The head/ear protection subsystem shall be designed to deflect falling liquids. It shall not be affected by:

(a) 82°C (180°F) water falling on it at a rate of 60 liters per minute (15.9 gallons per minute), from a sprinkler head from a height of 1.5 m (5 ft) for 10 minutes.

These criteria are straightforward and should be conducted directly as described. Commercial nozzles are available for the water impingement portion of the requirement.

The failure criterion consists solely of visual examination to confirm adequate deflection of the liquids and lack of any liquid on the inner surfaces of the helmet after exposure.

The helmet will be mounted on a headform, utilizing the normal chin-strap attachment fittings, to verify that the liquid impingement does not cause the helmet to be displaced during this exposure.

Weight

"The head/ear protection subsystem shall weigh a maximum of 850 grams (30 oz)."

This is also a straightforward requirement and should be evaluated on a scale of sufficient accuracy.

Fit and Retention

"A range of sizes, or an adjustment shall be provided so that the head/ear protection subsystem will fit all sizes and shapes of firefighter's heads and a variety of hair styles and lengths.

a) falls off the back step of an apparatus as the vehicle turns a 90° corner at 40 kilometers per hour (25 mph) and he is thrown off in a centrifugal direction;

b) if a shower of roofing gravel hits the outermost edge of the brim from a height of 6 meters (19.7 ft).

The retention system shall not cause injury when the brim is impacted by a 21 kg-m (152 ft-lb) impact load."

4.1.1 Head/Ear Protection Subsystem (Contd)

Evaluation for fit will consist of a visual examination of the ranges of size provided by the manufacturer. A convenient reference guide to headband size and circumferential measurement is found in the ANSI Z89.3 Standard for Industrial Head Protection. The helmets should be checked to insure that all sizes listed are included in the helmets supplied.

a) The stated situation will be duplicated using a helmeted headform mounted on a centrifuge. In this situation the subsystem must stay on the head when the brim is subjected to a 21 kg-m (152 ft-lb) impact load edge on.

b) This will be duplicated by mounting the helmet subsystem on a rigid headform attached firmly to the ground. A supply of roofing gravel sufficient to last 5 seconds would be poured from the required height to impact the edge of the brim. The helmet must not become dislodged from the headform under these conditions.

The last criteria can be duplicated by weight falling sufficiently close to the headform to just contact the edge of the helmet near the ear area. The helmet must under this impact condition, come free of the headform and not cause injury.

Service/Other Criteria

Maintainability

"The subsystems' maintenance shall be capable of being performed by firefighters at the fire station. If any process used requires curing, such as for adhesives or waterproofing, the curing shall be completely effective after 6 hours at room temperature."

This criterion requires a visual examination of the helmet to determine the method of construction. Those portions of the shell and ear protectors that may be damaged in time, and are replaceable, should be actually replaced, using the adhesives recommended to verify the 6 hour maximum curing time allowed in accordance with the manufacturer's recommended instructions.

Similarily, if polishing, waterproofing or cleaning agents are recommended by the manufacturer of the head protector, they should also be evaluated to assure satisfactory service.

4.1.1 Head/Ear Protection Subsystem (Contd)

Reliability and Durability

"The subsystem shall, at a minimum, satisfy all of the protection, performance, comfort, and service criteria pertinent, to it for a length of time equal to its service life."

"The subsystem shall be durable enough to provide service (as defined above) with a busy metropolitan fire company for a minimum time period of 5 years."

For this evaluation the subsystem will be subjected to cycles of water, heat, impact and flame. Following exposure to these environmental cycles the subsystem will be evaluated for retention of its original properties in the areas of:

- impact, puncture & cut resistance
- flame and heat resistance
- electrical protection

In addition, these tests will be supplemented by a one year field evaluation at a busy metropolitan fire house. Attention will be given to subjecting a sufficient number of samples to this evaluation so that the subsystem can be re-evaluated with a reasonable level of statistical significance.

Donning

"The head/ear protection subsystem must be capable of being donned and ready for use in 5 seconds."

This requirement will be evaluated by volunteer subjects.

Recognizability

"Head/ear protection subsystem shall be light in color and/or provided with retro-reflective surfaces to make it visible at distances up to 200 feet at night."

These requirements can be visually verified. The reflectivity of the surfaces shall be evaluated by subjecting the subsystem to the glare of automotive headlamps (on a dark night) at a distance of 200 feet. Under these conditions the subsystem markings shall be visible to an individual with $40/40^{3}$ vision in one or both eyes (with or without eyeglasses). Recognizability tests can also be con ducted in accordance with "Model Performance Criteria for Structural Firefighters' Helmets" (Ref 1).

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[3] This is the minimum vision requirement for obtaining an automotive driver's license in each of the states.

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4.1.1 Head/Ear Protection Subsystem (Contd)

Dryability

"Head/ear protection subsystem that has been immersed in water for 5 seconds shall be capable of being dried (95% of the absorbed water removed) in either of the following ways:

a) 6 hr of air drying at room temperature

b) 1 hr in a 95°C (203°F) oven.

In order to show that the design performance criteria has not been compromised, the electrical tests must be repeated after the dry out periods have been accomplished, and after the subsystem has undergone a total of 30 wet-dry cycles.

Acceptance

"The overall characteristics of the subsystem shall be acceptable to the firefighter and shall promote a desire to use the protection subsystem."

A representative group of firefighters shall be used for the evaluation of acceptance. If the majority agree that the subsystem is acceptable then the subsystem can be so considered.

Compatibility

"The head/ear protection subsystem shall incorporate a means to ensure that a compatible interface exists between it and,

a) the torso/limb protection subsystem (with particular attention given to the neck area),

b) the face/eye protection subsystem,

c) the Communication System,

d) the Breathing System,

e) the Lighting System.

4.1.1 Head/Ear Protection Subsystem (Contd)

There shall be no interference with donning and doffing and there shall be no resulting gaps that would permit ingress of debris or water."

To evaluate compatibility the subsystem will be tested in conjunction with all of the applicable interfacing subsystems and systems. Mutual accommodation, or interference, in fit and function will be assessed with the aid of a representative group of firefighters during the evaluation.

REFERENCES FOR SECTION 4.1.1

1. Model Performance Criteria for Structural Firefighters Helmets, National Fire Protection Control Administration, Aug 1977
2. American National Standard - ANSI 289.3 - 1969 Safety Requirements for Industrial Head Protection
3. American National Standard - ANSI Z24.22 - "Measurement of the Real Ear Attenuation of Ear Protectors; Method for."
4. Human Factors Study for Project FIRES (Phase I) - to be published, R. J. Del Vecchio, Grumman Aerospace Corp., 1978
5. American National Standard - ANSI Z90.1 - 1971 "Specifications for Protective Headgear for Vehicular Users."

4.1.2 Face/Eye Protection Subsystem

Face and eye protection are of great importance to the firefighter. Eye injuries must be prevented not only because of their potentially grievous nature, but also because the most minor temporary vision interference can cause further injury. Eye injuries are often permanent. There is no rehabilitation if eyesight is lost, and the firefighter is thus permanently disabled. Also, even a small particle will irritate the eye causing blinking and tearing. This will distract the firefighter, and may cause him to stumble or fall. Thus a minor annoyance can lead to a serious injury.

Aside from eye protection, the exposed face areas require protection from the myriad flying and falling objects that are found at the fire scene. Face and eye protection must be provided during all phases of work at the fire scene. The breathing apparatus facepiece normally provides protection, but when it might be removed for "mop-up" operations, such as overhaul, a separate face/eye protector, such as face shield or goggles, is required.

4.1.2.1 Requirements

Protection Criteria

Impact - Flying and falling objects such as masonry rubble, roofing stones and shingles, wooden splinters, nails and glass shards can all cause impact injuries to the firefighters face and eyes. Impact protection particularly must be provided from small objects which might pierce the eye. Large objects may cause damage to the face and eye areas but seem to be less likely to cause permanent eye damage. Also if impact protection were required against large objects the resultant protective apparatus would probably be too heavy to be practical. The following protective criteria have therefore been chosen to reflect realistic impact protection requirements:

- The face/eye protection subsystem shall withstand the impact of a brick falling 4 stories. There shall be no spalling or shattering of the protector in the rearward direction, that is, toward the face. This requirement shall be met before and after the protector has been subjected to the heat requirements of Class 1, 2, and 3 of Table 3-1, and after an equilibrium temperature of -50°C (-58°F) is achieved. This requirement is to be met both in the stowed and deployed positions.

Puncture - The objects listed above as potential causes of impact injuries can also be considered as capable of causing punctures. Just about any sharply pointed, falling object may pose a threat to the face/eye protection subsystem. In addition to pointed objects,

4.1.2 Face/Eye Protection Subsystem (Contd)

a danger exists that objects which might normally not puncture the protection equipment may do so if they are hot, or if the equipment itself is hot. The following requirements have taken these situations into consideration:

- The face/eye protection subsystem shall not be penetrated by the tip of a 4 penny nail impacting the subsystem with an energy of 1.4 kg-m (10-ft-lb). The requirement shall be met with the nail at room temperature and also with the nail at 60°C (140°F). These requirements shall be met before and after the subsystem has been subjected to the heat requirements of Class 1, 2, and 3 of Table 3-1, and after an equilibrium temperature of -50°C (-58°F) is achieved. This requirement is to be met both in the stowed and deployed positions.

Cuts and Scratches - The potential for cut and scratch damage exists wherever a sharp object strikes a glancing blow to the face/eye protection subsystem. Resistance to cuts and scratches is needed to insure service durability as well as to protect the firefighter.

- The outer surface of the face/eye protection subsystem shall not be cut nor suffer any surface impairment by the sharp edge of a metal venetian blind being drawn against the protector.
- The outer surface of the face/eye protection subsystem shall not suffer any impairment after being rubbed with a dirty, sandy firefighter's glove at moderate finger tip pressure over the width of the protection equipment, for 5 cycles.
- The above two requirements shall be met before and after the subsystem has been subjected to the heat requirements of Class 1, 2, and 3 of Table 3-1.

Flame - These requirements are given on Page 2/4-2.

Heat - Heat reaches the face/eye protection subsystem primarily through radiation, although conduction via hot air plays a role.

The characteristic fire scene thermal environments encountered by the firefighter are given in Table 1.

Based on these considerations the following design criteria are required for heat protection:

- The face/eye protection subsystem shall withstand each of the thermal environments of Classes 1, 2, and 3 without any visible distortion and subsequently meet all other requirements of this section. Under these conditions the inside surfaces of the protector in contact with the firefighter's face shall not exceed 45°C (113°F).

4.1.2 Face/Eye Protection Subsystem (Contd)

- When subjected to the Class 4 environment the face/eye protection subsystem shall remain intact. Under these conditions the inside surface temperatures of the protector in contact with the firefighter's face may not exceed the Figure 3-1 temperature-time limitations.

Electricity - These requirements are given on page 2/4-2.

Performance

Coverage and Visibility - The face/eye protection subsystem shall provide as much coverage as possible consistent with all other objectives. As a minimum, the following shall be provided:

- The face/eye protection subsystem shall, at a minimum, cover the eyes, nose, cheekbones and extend downwards from the helmet brim to approximately the upper lip. It shall extend backwards to approximately the temple area, and in no way shall it reduce the firefighters peripheral field of vision.
- The face/eye protection subsystem shall meet the latest revision of the optical performance requirements of the American National Standards Institute specification ANSI Z87.1. (Reference 1)
- Fog shall not be allowed to form on the inside surface of the protector nor should moisture condense thereon.

Comfort

Water Penetration - Every firefighter faces falling water which he may encounter from an open sprinkler head, or from a nozzle stream bouncing off walls and ceilings, or even from a driving rain. This water may be ice cold or it may be steaming hot. Under these conditions the firefighter's face and eyes must remain dry and the system must remain unaffected by the water. The following criterion for system performance is required:

- The face/eye subsystem shall not permit dripping water from a 3 m (9.8 ft) ceiling falling water from a 60 1/m (15.9 gpm) sprinkler head, driving water from a rainstorm, or deflected nozzle stream to enter the covered face area of the firefighter.

Weight - The weight of the face/eye protection subsystem must be as low as possible in order to least encumber the wearer, and to minimize fatigue when performing tasks. To this end, the following criterion is established:

- Total weight of the face/eye protection subsystem shall be a maximum of 170g (6 oz) including all fittings and attachments.

4.1.2 Face/Eye Protection Subsystem (Contd)

Fit - The face/eye protection subsystem must be comfortable to wear and must provide the same level of protection to all firefighters independent of their facial size or shape. To this end, the following criterion is required:

- The face/eye protection subsystem must be either adjustable, or available in different sizes to provide the same level of protection to all firefighters.

Service/Other

Maintainability - These requirements are covered on page 2/4-11.

Reliability - These requirements are covered on page 2/4-11.

Durability - These requirements are covered on page 2/4-11.

Donning/Doffing - It is anticipated that the face/eye protection subsystem be integrated with the head/ear protection subsystem, and be ready for use whenever the latter is worn. Also, there shall be no interference with donning and doffing any other subsystem as described below:

- The face/eye protection subsystem shall not increase the time-to-don or time-to-doff of any other piece of firefighters gear. It shall be capable of being deployed in 2 seconds, and shall be capable of being stowed in an out-of-the-way position within 3 seconds.

Acceptance - The requirements are covered on page 2/4-12.

Compatibility - To assure the effectiveness of the entire firefighters ensemble, it is necessary that all the component items function well together. To this end the following criteria are necessary:

- The face/eye protection subsystem shall incorporate a compatible interface between it and the head/ear protection subsystem, the Communications System, and the Lighting System.
- There shall be no interference with the Breathing System when the face/eye protection subsystem is in a retracted position.
- In either the retracted or deployed position the face/eye protection subsystem shall not interfere with water drainage from the head/ear protection subsystem. The protection subsystem shall not cause any channels or pockets to form where debris, smoke or water may accumulate or enter the other protective subsystems.

4.1.2 Face/Eye Protection Subsystem (Contd)

4.1.2.2 Test Methods

Protection Criteria

Impact

"The face/eye protection subsystem shall withstand the impact of a brick falling 4 stories. There shall be no spalling or shattering of the protector in the rearward direction, that is, toward the face. This requirement shall be met before and after the protector has been subjected to the heat requirements of Class 1, 2, and 3 of Table 3-1, and after an equilibrium temperature of -50°C (-58°F) is achieved. This requirement is to be met both in the stowed and deployed positions."

The impact test shall be conducted both before and after the Class 1, 2, and 3 heat exposure tests described later.

The test will be conducted on a impact machine with a flat striker as the impact weight. The machine will provide an impact velocity equivalent to the free velocity of the brick falling 4 stories or 12 m (39 ft). A suitable method of measuring the impact velocity will be provided. The fixture will provide a single impact by preventing impact weight bouncing. The striker will be secured to the drop device so as to impact the test item. The face/eye protection will be mounted on a head form constructed of an elastomer material, as in actual usage, with the point of impact being at approximately eye level. There shall be no cracking, chipping, or shattering of the protector which may injure the user.

Puncture - The puncture test shall be conducted both before and after the heat exposure testing (Class 1, 2, and 3) described in a later section, and after stabilizing the Subsystem at a temperature of -50°C (-58°F).

"The face/eye protection subsystem shall not be penetrated by the tip of a 4 penny nail impacting the protector with an energy of 1.4 kg-m (10 ft-lb.). The requirement shall be met with the nail at room temperature and also with the nail at 60°C (140°F)".

These requirements shall be met before and after the subsystem has been subjected to the heat requirements of Class 1, 2 and 3 of Table 3-1, and after an equilibrium temperature of -50°C (-58°F) is achieved. This requirement is to be met in both the stowed and deployed positions.

The penetration test will be conducted on a vertical drop machine to provide an impact energy of 1.4 kg-m (10 ft-lb.), using a suitable combination of impact mass and drop height.

4.1.2 Face/Eye Protection Subsystem (Contd)

The fixture will provide sufficient support of the penetration nail to preclude any possible bending. The fixture will also be designed to provide a single impact by preventing impact mass bouncing. The penetration test with the nail at 60°C (140°F) will include temperature measuring instrumentation. The face/eye protector will be mounted on a head form constructed of elastomer material with the point of nail impact being at approximately eye location.

Cut and Scratch - Testing shall be conducted both before and after the heat exposure testing (Class 1, 2 and 3) described in a later section.

"The outer surface of the face/eye protection subsystem shall not be cut nor suffer any surface impairment by the sharp edge of a metal Venetial blind being drawn against the protector".

A 30 cm (12 inch) length of the edge of a commercial Venetian blind will be drawn across the protector under its own weight at a rate of approximately 2.5 cm per sec (1 inch per sec.). The surface shall not show any indications of degradation.

"The outer surface of the face/eye protection subsystem shall not suffer any impairment after being rubbed with a dirty, sandy firefighter's glove with moderate finger tip pressure, for the width of the protector for 5 cycles".

To satisfy this requirement a used firefighter glove will first be submerged into a 50-50 mixture (by weight) of oil and fine sand (i.e., 140 mesh silica flour), then placed on a hand form, and rubbed across the full width of the protector at a contact pressure of 6.9 kilo pascals (1 psi) for a total of 5 cycles. The contact pressure will be assessed by measuring both the force applied by the handform and the glove's contact area with the protector. At the completion of the 5 cycles of rubbing and after cleansing the surface with soap and water, the surface of the protector shall not show any indication of degradation.

Flame Exposure

"The subsystem shall not ignite, burn, char, melt, or shrivel, or otherwise degrade when exposed to a 650°C (1200°F) flame for 5 seconds."

The face/eye protector will be exposed to an open 650°C (1200°F) flame. The use of any commercially available combustible gas for this test is acceptable. The gas flame will be directed at a 45 degree angle to the test item surface for a 5 second period. The burner flame will be approximately 1 cm (1/2 inch) high. Flame temperature will be measured by

4.1.2 Face/Eye Protection Subsystem (Contd)

the use of a thermocouple and instrumentation rated for at least 700°C (1291°F). All different components or materials of the face/eye protection subsystem (such as securing devices) will be exposed separately to the flame for the 5 second period.

The required flame temperature will be achieved by controlling the percentage of excess air or by the location of the test item from the flame, as long as the correct exposure temperature is verified.

Heat Exposure

A. "The face/eye protection subsystem shall withstand each of the thermal environments of Class 1, 2 and 3 without any visible distortion and subsequently meet all other requirements of this document. Under these conditions the inside surfaces of the protector in contact with the firefighters face shall not exceed 45°C (113°F)."

B. When subjected to the Class 4 environment the face/eye protection subsystem shall remain intact. Under these conditions the inside surface temperatures of the protector in contact with the firefighters face may not exceed the Figure 3-1 temperature-time limitations."

The "A" criterion exposure tests will be performed in a manner similar to that detailed in method 505 of MIL-STD-810. Radiant heat or lamps will be used with the radiant flux being measured by instrumentation such as a phyrheliometer, radiometer, etc. The test set up shall also include instrumentation for measuring the air temperature within the chamber.

For the evaluation of criterion "B" the test item will be subjected to a single exposure of the Class 4 environment. The test will be similar to that for the Class 1, 2 and 3 chamber, but modified for the higher temperature. The required chamber conditions will be attained and stabilized prior to the insertion of the test item for the 10 second period.

After exposure of the test item to the Class 1, 2 and 3 environments there shall be no degradation in the performance and protection requirements when tested as required in the other phases described. When subjected to the Class 4 environments the face/eye protection shall remain intact and provide the protective coverage as required.

During testing, the face/eye protection will be mounted on a head form attached to a helmet in the same manner occurring during actual usage.

4.1.2 Face/Eye Protection Subsystem (Contd)

Electricity

"The subsystem shall limit the current flow to less than 3 milliamperes when there is a 2200 volt AC electrical potential between the subsystems outer surface and the part of the body it is in contact with. This criterion shall be met with the outer surface of the subsystem either wet or dry."

"The stated protection shall be provided at room temperature as well as:

a) immediately after the subsystem has been subjected to the Class 2 and 3 thermal environments, and

b) after the subsystem has achieved an equilibrium temperature of -50°C (-58°F)." R

This test will be conducted using two electrodes which are interconnected into an insulation resistance test apparatus. The apparatus shall have the capability of applying 2200 volts AC and monitoring leakage currents in the range of 0 to 10 milliamperes.

The face/eye subsystem shall be subjected to the thermal environments described above and the electrodes pressed against opposite sides of the protector. Leakage currents in excess of 3 milliamperes shall be considered a failure.

For the evaluation of a wet subsystem the protector shall be wetted by 82°C (180°F) water for 5 minutes at the rate of 60 l/m (15.9 gals per min) prior to testing.

Performance Criteria

Coverage and Visibility

"The face/eye protection subsystem shall cover the eyes, nose, cheek bones and extend downwards from the helmet brim to approximately the upper lip. It shall extend backwards to approximately to the temple area."

The face/eye protector shall be mounted, as it is intended to be worn, on a head form of typical anthropomorphic dimensions to verify conformance with this requirement.

"The face/eye protection subsystem shall meet the optical performance requirements of the American National Standards Institute specification ANSI Z87.1, latest revision".

The optical performance requirements of ANSI Z87.1 include the following areas: range of vision, transmittance, haze (for plastics), quality of manufacture, and optical quality. A visual examination of the protector for quality of manufacture should indicate obvious defects, such as, smoothness of interior and exterior surfaces, bubbles, waves or other flaws which would impair vision. The degree of haze for plastic protectors will be

4.1.2 Face/Eye Protection Subsystem (Contd)

conducted using Federal Test Methods Standard 406. Optical quality in terms of prismatic and refractive effects of lenses will be checked by the applicable NBS methods. The protector will also be checked to ensure that there is no interference with corrective lenses which may be worn by fire fighting personnel.

"Fog shall not be allowed to form on the inside surface of the protector nor should moisture condense thereon."

This evaluation can be conducted with the aid of a test subject and an environmental chamber. The subject shall be made to utilize the protector (properly installed on a head/ear protection subsystem) while in an environmental chamber which is kept at a 20°F air temperature. During this exposure the subject shall jog in place (at the rate of 116 steps per minute) for two ten-minute periods separated by a ten minute rest period. During this time, there shall be no evidence of fog formation or moisture condensation on the inside surface of the face/eye protector.

Comfort Criteria

Water Penetration

"The face/eye subsystem shall not permit dripping water from a 3 m (9.8 ft) ceiling, falling water from a 60 1/m (15.7 gpm) sprinkler head, driving water from a rainstorm or deflected nozzle stream to enter the covered face area of the fire fighter."

The face/eye protector along with a head/ear protector will be placed on a head form and located beneath a commercially available fire system sprinkler head designed to provide the required flow rate. The head form test assembly will then be subjected to the water flow for 5 minutes. At the end of this time the protector will be removed and the head form examined for traces of water in the face/eye area. Evidence of water in the face/eye area will be considered a failure.

Weight

"The total weight of the face/eye protection subsystem shall be 170g (6 oz) including all fittings and attachments".

The assembly shall be weighed on a balance.

Fit

"The face/eye protection subsystem must be either adjustable, or available in different sizes to provide the same level of protection to all fire fighters".

Conformance with this requirement will be determined by visual examination and fit on personnel. Dimensional analysis will be conducted to ensure proper size identification.

4.1.2 Face/Eye Protection Subsystem (Contd)

Service/Other Criteria

Maintainability

"The subsystems maintenance shall be capable of being performed by firefighters at the fire station. If any process used requires curing, such as for adhesives or waterproofing, the curing shall be completely effective after 6 hours at room temperature".

Verification of maintainability will be achieved primarily by visual examination. Cleaning, disinfecting, waterproofing, lense polishing or replacement operations will be performed, using only equipment provided by the manufacturer, to ensure ease of performance. Operations which require application of adhesives or water proofing will be performed to verify curing within the required 6 hour period.

Reliability and Durability

"The subsystem shall, at a minimum, satisfy all of the protection, performance, comfort, and service criteria pertinent to it for a length of time equal to its service life."

"The subsystem shall be durable enough to provide service (as defined above) with a busy metropolitan fire company for a minimum time period of 5 years."

For this evaluation the subsystem will be subjected to cycles of water, heat, impact and flame. Following exposure to these environmental cycles the subsystem will be evaluated for retention of its original properties in the areas of:

- impact, puncture and cut resistance
- flame and heat resistance
- electrical protection

In addition, these tests will be supplemented by a one year field evaluation at a busy metropolitan fire house. Attention will be given to subjecting a sufficient number of samples to this evaluation so that the subsystem can be re-evaluated with a reasonable level of statistical significance.

Donning/Doffing

"The face/eye protection subsystem shall not increase the time-to-don or time-to-doff of any other piece of firefighters gear. It shall be capable of being deployed in 2 seconds, and shall be capable of being stowed in an out-of-the-way position within 3 seconds."

This requirement will be evaluated by volunteer subjects.

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4.1.2 Face/Eye Protective Subsystem (Contd)

Acceptance

"The overall characteristics of the subsystem shall be acceptable to the firefighter and shall promote a desire to use the protection subsystem."

A representative group of firefighters will be used for the evaluation of acceptance. If the majority agree that the subsystem is acceptable then the subsystem can be so considered.

Compatibility

"The face/eye protection subsystem shall incorporate a compatible interface between it and the head/ear protection subystem, the Communications System, and the Lighting System."

"There shall be no interference with the Breathing System when the face/eye protection subsystem is in a retracted position."

"In either the retracted or deployed position the face/eye protection subsystem shall not interfere with water drainage from the head/ear protection subsystem. The protection subsystem shall not cause any channels or pockets to form where debris, smoke or water may accumulate or enter the other protective subsystems."

To evaluate the compatibility of this subsystem it will be tested in conjunction with the head/ear protection subystem, the Communication System and the Self Contained Breathing System for mutual accommodation, or interference, in fit and function. A representative group of firefighters will be used for this evaluation.

REFERENCES FOR SECTION 4.1.2

1. American National Standard - ANSI 287.1 - 1965, "Practice for Occupational and Educational Eye and Face Protection."

2. Federal Test Methods Standard 406.

4.1.3 Torso/Limbs Protection Subsystem

The protection of the torso, limbs, and neck are considered part of this subsystem. The subsystem must protect the firefighter against the heat, water, sparks, flame, and sharp and abrasive surfaces that may be encountered. It must be easily and quickly donned, be comfortable, durable, distinctive, and as lightweight and non-constrictive as possible.

4.1.3.1 Requirements

Protection Criteria

Impact - The structural firefighting environment is filled with falling objects. Rubble, ceiling tiles, wood brands, joists, pieces of conduit, and electrical fixtures, represent some of the debris that may rain down and cause impact injuries. The body protection that might be required to protect against all of these hazards would probably be too heavy and encumbering to be practical. However, it is reasonable to expect some impact protection for the torso and limbs, particularly in the shoulder, knee, and elbow areas. To this end, the following criteria shall be adopted:

- The upper torso (shoulders and back) shall be protected from the impact of a 2 kg (4.4 lb) slab of plaster falling on the firefighter from a 3 m (9.8 ft) ceiling. No bruising of the skin shall result.
- A fully-turned-out firefighter (wearing breathing apparatus) shall not suffer any bruises if he/she stumbles to his/her knees from a walking position
- When wearing the protection subsystem, a firefighter's elbows shall not be bruised when bumped against stationary objects.

Puncture - Many of the falling objects encountered at the fire scene present potential puncture hazards. Nails protruding from falling peices of wood, glass slivers, and pointed fragments of masonry are typical items that may strike the torso. Puncture protection is required also to assure that the garment has good snag and tear resistance. Thus the following criterion is imposed:

- The torso/limbs protection subsystem shall not be punctured when a firefighter leans against the protruding point of a 4-penny nail, with a force of 10 kg (22 lb).

Cut - The torso and limbs can be cut by many objects met at the fire scene. For example, the firefighter can brush against sharp edges of sheet metal, severed conduit, protruding nail points, and broken pieces of glass. Cut protection must be provided

4.1.3 Torso/Limbs Protection Subsystem (Contd)

against these hazards, and, in addition, good resistance to cutting will result in a garment with good integrity which will not have sites where tearing can be initiated. For this requirement, the following criterion shall be applied:

- The torso/limbs protection subsystem shall not be cut by the edge of a protruding piece of sheet metal when the edge is contacted by the garment, when worn by a firefighter moving at 6 km/h (3.7 mph)

Flame - The requirements are covered in Page 2/4-2.

Heat - The fire scene thermal environments encountered by the firefighter are characterized by four combinations of exposure time, temperature, and flux, as shown in the Table 3-1.

Based on these considerations the following criteria are required for thermal protection:

- The torso/limbs protection subsystem shall withstand each of the thermal environments of Classes 1, 2 and 3 and subsequently meet all other requirements of this section, without any of the inner surface of the subsystem that contacts the torso reaching 45°C (113°F), the pain threshold.
- When subjected to the Class 4 environment, the inner surfaces of the torso/limbs protection subsystem shall not exceed the Figure 1 temperature-time limitations.
- After having been showered with 82°C (180°F) water at a rate of 60 liters per minute (15.9 gallons per minute) for 10 minutes the subsystem shall withstand the thermal environments of Class 1, 2 and 3 without resulting in steam vapor temperatures on the inside of the protector that exceeds 45°C (113°F). Under Class 4 conditions and after showering with water as described above any steam vapor present in the inside of the protector shall not exceed the Figure 1 temperature-time limitations.

Conductive Heat - Firefighters may encounter hot water or glowing embers when they kneel or crawl, and thus the following conductive heat protection is required:

- The firefighter shall be able to kneel on a hot surface of 121°C (250°F) for 10 minutes without the inner surface of the garment reaching 45°C (113°F), the pain threshold.

4.1.3 Torso/Limbs Protection Subsystem (Contd)

- After showering the subsystem with 82°C (180°F) water at a rate of 60 liters per minute (15.9 gallons per minute) for 10 minutes the firefighter shall be able to kneel on a 121°C (250°F) hot surface for 10 minutes without resulting in steam vapor temperatures on the inside of the protector greater than 45°C (113°F), the pain threshold.

Electricity - These requirements are covered on Page 2/4-2.

Performance

- Mobility - The firefighter must be able to climb, walk, run, bend, kneel, stretch and reach or crawl with minimum hindrance. The following criteria provide a job-related physiological basis for assessing torso protection ability:
  - When wearing the torso/limbs protection subsystem the firefighter shall be able to climb a flight of stairs at an energy expenditure no more than 10% greater than when wearing street clothes alone.
  - The torso/limbs protection subsystem shall allow a range of motion which is 95% of the range of motion of a firefighter without the subsystem.

Comfort

Cold Insulation - In extreme weather the firefighter may be forced to work in snow and sleet, or may be required to wait out-of-doors before entering an involved building. The winter environment leads to the following cold insulation criterion:

- The torso/limbs protection subsystem shall incorporate a means of protection against extreme winter cold. A firefighter shall be able to be exposed for 30 minutes to -23°C (-9.4°F) environment and a wind chill factor of -50°C (-58°F), while wearing the protection subsystem. The winter protection shall not compromise any of the performance requirements of this document.

Heat Insulation - The firefighter must be able to perform tasks in summer heat as well as winter cold. While summer temperatures and solar radiation do not lead to frostbite or other severe injuries, the combination of heat, humidity, solar radiation, and workload can result in high metabolic loads and sweat production rates. Under these conditions, a firefighter may experience heat exhaustion and/or dehydration, and/or cardiac distress. Thus, it is important that the stress imposed by the torso/limbs protector shall be minimized. This leads to the following criterion:

4.1.3 Torso/Limbs Protection Subsystem (Contd)

- When worn by a firefighter on a hot summer day (i.e., at 95° F, 80% relative humidity, wind velocity less than 5 mph, and a solar radiance of 0.1 watt/cm^2) the torso/limb protector shall not increase the firefighters energy expenditure by more than 10% compared to the firefighter wearing street clothes alone.

Water Penetration and Absorption - Every working firefighter faces the danger of falling or splashing water. The protection equipment must provide a barrier between the individual and this hazard. The following criteria will assure that the torso/limbs protection subsystem meets the firefighters' requirements when faced with water at the fire ground:

- The torso/limbs protection subsystem shall not be wet on the inside when it is subjected to 82° C (180° F) water falling on it at a rate of 60 1/m (15.9 gallons per minute), from a sprinkler head at a height of 3m (9.8 ft), for 10 minutes
- The weight of the torso/limbs protection subsystem shall not increase more than 5% after being subjected to the previous environment
- The torso/limbs protection subsystem shall allow the body's perspiration to escape. Perspiration absorbed by the protector shall not exceed the quantity retained by a firefighters street clothes by more than 50% while the firefighter is climbing stairs for 3 minutes at a rate of 116 steps per minute (approximately 580 Kcal/hr (2300 Btu/hr) heat production).

Weight - The weight of the torso/limbs protection subsystem must be as low as possible to provide the least encumberance to the wearer, and to minimize fatigue when performing tasks. To this end, the following criterion is required:

- Total weight of the torso/limbs protection subsystem shall not exceed 2.3 kg (5.0 lb) for the 95th percentile firefighter

Fit

- Torso/limbs protection subsystem shall be available in numerical sizes.

Service/Other Criteria

Maintainability - These requirements are given on Page 2/4-11.

Reliability - These requirements are given on Page 2/4-11.

Durability - These requirements are given on Page 2/4-11.

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Donning/Doffing

- The torso/limbs protection subsystem must be capable of being donned in 10 seconds and being removed rapidly from an injured or unconcious person.

Recognizability - To aid in identification of firefighters, the following requirements are imposed:

- The torso/limbs protection subsystem shall be provided with retro-reflective surfaces to make it visible at distances up to 200 feet at night.
- A range of colors shall be provided and provision shall be made for indicating rank, task, organization, etc.

Dryability

- After the torso/limbs protection subsystem has been subjected to the water penetration and absorption requirements it shall be capable of being dried (95% of the absorbed water removed), in either of the following ways:
  a) 6 hr of air drying at room temperature
  b) 1 hr in 95°C (203°F) oven.

Acceptance - These requirements are given on Page 2/4-12.

Compatibility - To assure the effectiveness of the entire firefighters' ensemble, it is necessary that the component items function well together. To this end, the following criteria are necessary:

- A compatible interface must be insured between the torso/limbs protection subsystem and,
  a) the head/ear protection subsystem (with particular attention given to the neck area)
  b) the face/eye protection subsystem
  c) the foot/ankle protection subsystem
  d) the hand/wrist protection subsystem
  e) the Self Contained Breathing System
  f) the Communication System

4.1.3 Torso/Limbs Protection Subsystem (Contd)

g) the Personal Cooling System

h) the Lighting System.

The interfaces must not allow accumulation of debris, particularly at the wrists and ankles and neck. No exposed skin shall be permitted at the wrists and ankles.

4.1.3.2 Test Methods

Impact

a) "The upper torso (shoulders and back) shall be protected from the impact of a 2 kg (4.4 lb) slab of plaster falling on the fire fighter from a 3m (9.8 ft) ceiling. No bruising of the skin shall result.

b) A fully-turned-out firefighter (wearing breathing apparatus) shall not suffer any bruises if he/she stumbles onto his/her knees from a walking position.

c) When wearing the protection subsystem a firefighter's elbows shall not be bruised when bumped against stationary objects."

An anthropomorphic dummy will be fitted with the torso and limb protection subsystem. The dummy will have load transducers imbedded in the top shoulder area and the output of the transducers will be continuously recorded. Similar transducers will be imbedded in the upper back area and similarly recorded.

The dummy will be positioned so that a freely falling impactor will strike the shoulder. The impactor will weigh 2 kg (4.4 lb) and be approximately 5 inches long and 1 inch thick. It will be dropped from the required height so that the flat 1 inch side impacts the shoulder, without touching the head or neck.

The dummy will then be repositioned into a prone attitude and the test repeated with the impactor striking the back area. The failure criteria will be pressure levels in excess of 68.9 kilo pascals (10 psi) which are great enough to cause bruising.

The (b) and (c) hazard situations will be evaluated by a similar test except that the instrumented dummy will be made to impact the knee and elbow areas, respectively. For the evaluation of the "C" criterion the stationary object used for the test shall be an impactor which simulates the edge of a large metal door. For the purposes of both the "B" and "C" criteria evaluations load transducers will be used, and placed in the impact areas, and pressure levels great enough to cause bruising i.e., in excess of 68.9 kilo pascals (10 psi) will be used as the failure criterion.

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Puncture

"The torso and limbs protection subsystem shall not be punctured when a firefighter leans against the protruding point of a 4 penny nail, with a force of 10 kg (22 lb)."

Evaluation of this criterion will be accomplished on a swatch of material removed from an area of the subsystem and mounted in a test fixture. A 4 penny nail, also mounted in the fixture, will be forced against the swatch of material and the force during penetration recorded. The test will be repeated on several swatches from the subystem including the arm, back and apron sections. Penetration of the swatches at forces less than 10 kg (22 lbs) will be considered a failure.

Cut

"The torso and limb protection subsystem shall not be cut by the edge of a protruding piece of sheet metal when the edge is contacted by the garment at a walking speed of 6 km/h (3.7 mph)."

To evaluate this criterion a swatch of the subsystem material will be mounted on a mandrel and a length of sheet metal, on its edge, drawn across the swatch at a velocity of 6 Km/hr (3.7 mph). The sheet metal will be 21 gauge, its edge will be sharpened to a 60 degree angle, and a 10 kg (22 lb) force will be applied to it as it is drawn across the swatch.

Complete cutting through of the subsystem fabric will be considered a material failure.

Flame

"The subsystem shall not ignite, burn, char, melt or shrivel, or otherwise degrade, when exposed to 650°C (1200°F) flame for 5 seconds."

This requirement will be met through a flame impingement test where a commercially available natural gas nozzle is employed. The nozzle will be fed with natural gas and a 320% excess air mixture in order to achieve the required flame temperature. The nozzle will be hand held and the flame temperature checked with an appropriate thermocouple junction to verify the proper temperature location. The flame will be directed at the torso/limb and any other features, such as pocket flaps. The flame will be directed at any surface at a 45 degree angle from normal to that surface. Each surface will be exposed for a 5 second period.

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Heat

"The torso/limbs protection subsystem shall withstand each of the radiated heat environments of Classes 1, 2, and 3 without any visible distortion and without any of the inner surface of the subsystem that contacts the torso reaching 45°C (113°F) (pain threshold).

"When subjected to the Class 4 environment the inner surfaces of the torso/limbs protection subsystem shall not exceed the Figure 3-1 temperature-time limitations."

"After having been showered with 82°C (180°F) water at a rate of 60 liters per minute (15.9 gallons per minute) for 10 minutes the subsystem shall withstand the thermal environments of Class 1, 2 and 3 without resulting in steam vapor temperatures on the inside of the protector that exceed 45°C (113°F). Under Class 4 conditions and after showering with water as described above any steam vapor present in the inside of the protector shall not exceed the Figure 3-1 temperature-time limitations."

The first criterion exposures can be performed in a manner similar to that detailed in method 505 of MIL-STD-810 for heat build up, with appropriate modifications to accommodate the desired air temperature, radiant flux and exposure times. For the evaluation of this criterion a portion of the subsystem, a swatch, will be mounted on an insulated box and appropriately instrumented with thermocouples. This test ensemble will then be placed into an oven to be subjected to the required environmental conditions. The conditions will first be established in the oven and then the test sample momentarily placed therein for the required exposure period. No visible degradation of the materials nor temperatures in excess of 45°C (113°F) is permitted under the first criterion environmental conditions.

Evaluation of the second criterion can be accomplished by extension of the methods used above. In this case, however, temperatures exceeding the limits presented in Figure 1 constitute a subsystem failure.

The last criterion can also be performed by an extension of the above methods. The material swatch, though, shall be showered with water at the stated conditions before being subjected to the various thermal environments. In this case the failure criteria are steam temperatures in excess of 45°C (113°F) under Class 1, 2, or 3 conditions, and temperatures greater than those allowed per Figure 3-1 under Class 4 conditions.

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Conductive Heat

"The firefighter shall be able to kneel on a hot surface of 121°C (250°F) for 10 minutes without the inner surface of the garment reaching 45°C (113°F) (pain threshold)."

"After showering the subsystem with 82°C (180°F) water at a rate of 60 liters per minute (15.9 gallons per minute) for 10 minutes the firefighter shall be able to kneel on a 121°C (250°F) hot surface for 10 minutes without resulting in steam vapor temperatures on the inside of the protector greater than 45°C (113°F), the pain threshold."

A portion of the garment from the knee area will be removed and mounted on a mandrel. Thermocouples will be attached to the inner surface such that the thermocouples are pressed between the garment and the mandrel. The thermocouple outputs will be monitored continually during the exposure period.

The mandrel/test item assembly will be pressed on to a 121°C (250°F) surface with a force of 90 kg (198 lb) which corresponds to the 95th percentile weight of typical firefighters.

The failure criterion would be any indication of temperature above 45°C (113°F).

The second requirement can be evaluated by an extension of the previous method. In this instance, however, the mandrel will have a series of small, evenly spaced holes incorporated into it to allow the escape of steam vapors from the inside of the garment swatch. Thermocouples will be placed in these air-passages so that although the mandrel/test item assembly is pressed on to the 121°C (250°F) surface with a force of 90 kg (198 lb) the thermocuple will measure the vapor temperature in the passages. Before subjecting the garment to the combined effects of heat and force, however, the outer surface of the garment shall be showered with 82°C (180°F) water at a rate of 60 liters per minute (15.9 gallons per minute) for 10 minutes. The failure criterion would be any indication of temperature above 45°C (113°F).

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Electricity

"The subsystem shall limit the current flow to less than 3 milliamperes when there is a 2200 volt A.C. electrical potential between the subsystems outer surface and the part of the body it is in contact with. This criterion shall be met with the outer surface of the subsystem either wet or dry."

"The stated protection shall be provided at room temperature as well as:

a) immediately after the protection subsystem has been subjected to the Class 2 and 3 thermal environments described in Table I, and

b) after the protection subsystem has achieved an equilibrium temperature of $-50^{o}C$ ($-58^{o}F$).

The test can be conducted by providing two plate electrodes, each with approximate dimensions of 7.6 m (3 in.) square, which are incorporated into an insulation resistance test apparatus. The apparatus shall be capable of applying 2200 VAC and monitoring the leakage current.

A section from the garment shall be subjected to the conditions described above and the electrodes pressed against opposite sides of the garment fabrics. Current flows in excess of 3 milliamperes are considered failures. For evaluation of a wet garment, the material swatch shall be wetted by $82^{o}C$ ($180^{o}F$) water for 5 minutes, shaken dry, and then tested.

Comfort Criteria

Cold Insulation

"The torso and limb protection subsystem shall incorporate a means of protection against extreme winter cold. A firefighter shall be able to be exposed for 30 minutes to $-23^{o}C$ ($-9.4^{o}F$) environment and a wind chill factor of $-50°C$ ($-58°F$), while wearing the protection subsystem. The winter protection shall not compromise any of the performance requirements of this document".

4.1.3 Torso/Limbs Protection Subsystem (Contd)

In order to ensure the torso and limb protection subsystem's ability to protect the firefighter against extreme winter cold, the subsystem will be placed on a dummy and placed into a chamber for 15 minutes which is maintained at the required temperature and wind chill. During the test a sensible heat load shall be emitted by the dummy. This may be achieved by circulating hot water through the dummy to generate the required heat emission. The temperature of the dummy shall be monitored at several areas including the elbow, forearm, shoulder, chest and back. During the 15 minute period, the temperature shall not be allowed to drop below 18°C (64°F) at any one location. A graph plot of temperature versus time will be provided for the various locations.

Heat Insulation -

"When worn by a firefighter on a hot summer day (i.e., at 95°F, 80% relative humidity, wind velocity less than 5 mph, and a solar radiance of 0.1 watt/cm^2) the torso/limb protector shall not increase the firefighters energy expenditure by more than ten percent compared to the firefighter wearing street clothes alone."

For this evaluation an environmental chamber is required for performing the test procedure described in Reference 1. This procedure will be utilized on a test subject first clothed in street clothes, and then in the torso/limb protector. Energy expenditures with the protector worn shall not exceed those with street clothes alone by more than 10%. (For the purposes of this experiment street clothes consist of underwear, shirt, pants, socks and low cut shoes.)

Water Penetration and Absorption

"The torso and limb protection subsystem shall not be wet on the inside when it is subjected to 82^{o}C (180^{o}F) water falling on it at a rate of 60 litres/min (15.9 gallons per minute), from a sprinkler head from a height of 3 m (9.8 ft) for 10 minutes".

"The weight of the torso and limb protection shall not increase more than 5% after being subject to this environment."

The torso and limb protection subsystem will be placed on a dummy and located directly beneath a commercially available fire system sprinkler head designed to provide the required flow rate. The sprinkler will be 3 m (9.8 ft.) above the head of the dummy.

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Typical type head gear will be used during testing. The water delivered to the sprinkler will be at the required temperature. A drip pan will be placed inside the torso and limb protection subsystem, at the bottom, to provide indication of any water entering the subsystem, but not absorbed. This water may be absorbed by the firefighter's service uniform. This quantity of water will be measured.

The weight of the protection will be measured prior to and after the test. Any weight increase, any indication of coat leakage or areas of absorption shall be recorded.

Weight

"Total weight of the torso and limb protection subsystem shall not exceed 2.3 kg (5.0 lb) for the 95th percentile firefighter."

This requirement will be tested with a suitable scale.

Fit

"Torso and limb protection shall be available in the numerical sizes. Sizes of small, medium, and large are unacceptable".

Conformance with this requirement would be determined by dimensional examination to ensure proper size identification. The subsystems dimensions shall conform to accepted anthropomorphic values.

Service/Other Criteria

Maintainability

"The subsystems maintenance shall be capable of being performed by firefighters at the fire station. If any process used requires curing, such as for adhesives or waterproofing, the curing shall be completely effective after 6 hours at room temperature."

Verification of maintainability will be achieved primarily by visual examination. Cleaning, waterproofing, patching, will be performed using equipment only provided by the manufacturer. Operations which require application of adhesives or waterproofing will be performed to verify curing within the required 6 hour period.

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Reliability and Durability

"The subsystem shall, at a minimum, satisfy all of the protection, performance, comfort, and service criteria pertinent to it for a length of time equal to its service life."

"The subsystem shall be durable enough to provide service (as defined above) with a busy metropolitan fire company for a minimum time period of 3 years."

For this evaluation the subsystem will be subjected to cycles of water, heat, impact and flame. Following exposure to these environmental cycles the subsystem will be evaluated for retention of its original properties in the areas of:

- impact, puncture & cut resistance
- flame and heat resistance
- electrical protection

In addition, these tests will be supplemented by a one year field evaluation at a busy metropolitan fire house. Attention will be given to subjecting a sufficient number of samples to this evaluation so that the subsystem can be re-evaluated with a reasonable level of statistical significance.

Donning/Doffing

"The torso/limbs protection subsystem must be capable of being donned in 10 seconds and of being removed rapidly from an injured or unconcious person."
This requirement will be evaluated by volunteer subjects.

Recognizability

"The torso/limbs protection subsystem shall be provided with retro-reflective surfaces to make it visible at distances up to 200 feet at night."

"A range of colors shall be provided and provision shall be made for indicating rank, task, organization, etc."

These requirements can be visually verified. The reflectivity of the surfaces shall be evaluated by subjecting the subsystem to the glare of automotive headlamps (on a dark night) at a distance of 200 feet. Under these conditions the subsystem markings shall be visible to an individual with 40/40 vision in one or both eyes (with or without eyeglasses). Recognizability tests can also be conducted in accordance with "Model Performance Criteria for Structural Firefighter Helmets" (Ref 1).

4.1.3 Torso/Limbs Protection Subsystem (Contd)

Dryability

"After the torso/limbs protection subsystem has been subjected to the water penetration and absorption requirements it shall be capable of being dried (95% of the absorbed water removed) in either of the following ways:

a) 6 hr of air drying at room temperature
b) 1 hr in a 95°C (203°F) oven."

To perform this test the subsystem, after having been appropriately wetted (per the water penetration and absorption requirements specified in this section), should be allowed to drip dry at room temperature for three minutes before being weighed and then dried as follows:

a) placed in an oven preheated to and then maintained at 95°C (203°F). The subsystem shall remain in the oven for 20 minutes. At the end of this time the subsystem shall be removed and weighed. Or

b) placed in an environmental chamber at 15°C (59°F) and 70% RH for a 3 hour period. At the end of this time the subsystem should be removed and then weighed.

Inability to remove 95% of the absorbed water shall be considered a subsystem failure.

Acceptance

"The overall characteristics of the subsystem shall be acceptable to the firefighter and shall promote a desire to use the protection subsystem."

A representative group of firefighters will be used for the evaluation of acceptance. If the majority agree that the subsystem is acceptable then the subsystem can be so considered.

Compatibility

"A compatible interface must be insured between the torso/limbs protection subsystem and,

a) the head/ear protection subsystem (with particular attention given to the back area)

b) the face/eye protection subsystem

2

4.1.3 Torso/Limbs Protection Subsystem (Contd)

c) the foot/ankle protection subsystem

d) the hand/wrist protection subsystem

e) the Self Contained Breathing System

f) the Communication system

g) the Personal Cooling System

h) the Lighting System"

To evaluate compatibility the subsystem will be tested in conjunction with all of the applicable interfacing subsystems and systems. Mutual accommodation for interference, in fit and function will be assessed with the aid of a representative group of firefighters during the evaluation.

REFERENCES FOR SECTION 4.1.3

1. Human Factors Study for Project FIRES (Phase I) - To be published, R. V. Del Vecchio - Grumman Aerospace Corp - 1978

4.1.4 Hand/Wrist Protection Subsystem

The firefighter's hands must be protected from a variety of hazards including heat, sparks, embers, hot and cold water, glass, splinters, sharp cutting objects, and electrical shock. The hand/wrist protection subsystem must afford dexterity to the fingers as well as provide a gripping surface to enable the firefighter to perform his tasks. The subsystem must have proper fit, be comfortable, dry easily, be durable and be easily and quickly donned.

4.1.4.1 Requirements

Protection Criteria

Impact - Protection against the impact of small chunks of falling plaster, or small pieces of wood, or of doors closing on the back of a hand or wrist is required. For this requirement the following criterion is established.

- The hand/wrist protection subsystem shall protect against a 2 kg (4.4 lb) slab of plaster falling from a ceiling height of 4 m (13.1 ft) and landing on the back of the hand. Under these conditions there shall be no injury to the back of the hand.

Puncture - Punctures can occur from wood splinters, glass slivers, and nails. The following criterion is adopted:

- The hand/wrist protection subsystem should protect against the penetration of a 4-penny nail when the applied force is 45 kg (99 lb).

Cuts - A firefighter's hands may be cut when reaching through a broken window, resting on broken glass, or removing or pulling on a sharp edged piece of sheet metal or wire lath. Based on likely events such as these, the following criterion is adopted:

- The hand/wrist protection subsystem shall not be cut through when a 45 kg (99 lb) force is applied on a sharp edge with the palm side of the subsystem.

Electricity - These requirements are covered on Page 2/4-2.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

Heat - The two modes of heat transfer that are of primary concern for the hand/wrist protection subsystem are: a) the fire scene thermal environments that affect the back side of the hand, and b) conduction from a hot object to the palm side of the hand.

a) Fire Scene Thermal Environments - The fire scene thermal environments may be characterized by four combinations of exposure time, temperature and flux as shown in the table on Page 2/3-6.

Based on these considerations the following criteria are required for thermal protection:

- The hand/wrist protection subsystem shall withstand each of the thermal environments of Classes 1, 2 and 3 and subsequently meet all other requirements of this section without any of the inner surface that contacts the hand or wrist reaching 45°C (113°F), the pain threshold.
- When subjected to the Class 4 environment the inner surfaces of the hand protection subsystem shall not exceed the time-temperature limits presented in Figure 3-1.
- After being subjected to an external water pressure of 27.6 kilo pascals (4 psi) for one minute the subsystem shall withstand the thermal environments of Class 1, 2 and 3 without resulting in steam vapor temperatures on the inside of the protector that exceed 45°C (113°F). Under Class 4 conditions and after exposure to water as described above any steam vapor temperatures present on the inside of the protector shall not exceed the time-temperature limits presented in Figure 3-1.

b) Conduction

- When dry, the inside surface of the hand/wrist protection subsystem shall be maintained below 45°C (113°F) during and after contact of the palm side with hot objects of 510°C (950°F) for 5 seconds at grip pressures of 27.6 kilo pascals (4 psi) without degradation.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

- After subjection to an external water pressure of 27.6 kilo pascals (4 psi) for one minute, and both during and after contact of the palm side with hot objects of 510°C (950°F) for 5 seconds at grip pressures of 27.6 kilo pascals (4 psi), any steam vapor temperatures on the inside of the protector shall be less than 45°C (113°F). The inside surface of the protector shall also be maintained below 45°C (113°F), the pain threshold.

Flame Resistance - These requirements are given on Page 2/4-2.

Performance Criteria

Dexterity - The firefighter is called upon to perform many tasks at the fire ground which require dexterity. The tasks require coarse and fine grips and finger manipulation. The tasks include:

- Using tools such as power saws, axes, pikes, hammers, etc.
- Operating equipment like hose nozzles, fire extinguishers, breathing systems, lock removal equipment, etc.
- Sundry tasks involving ladder climbing, door opening, etc.

In the performance of any of the above, the fingers are used to:

- Provide rotational motion for the knobs on communication equipment or for handles on valves
- Depress buttons
- Aid in the grasping of objects
- Manipulating and transferring of various sized objects.

A test has been previously developed to measure and compare dexterity. This procedure, called The Bennett Dexterity Test, involves grasping, transferring objects and the use of tools, simulating many of the motions and tasks performed by firefighters. The following criterion is adopted to make use of this test.

- The hand/wrist protection subsystem shall allow the firefighter to perform the Bennett Dexterity Test (Ref 1), while wearing the subsystem either wet and dry, at a time increase of 30% over the baseline (bare-handed) time.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

Grip - As is the case for dexterity, good grip is required for many firefighting tasks such as swinging an axe and operating the power saw. This capability should be provided when the hand/wrist protection subsystem is either dry or wet. Thus, the following criterion is established:

- The firefighter wearing the hand/wrist protection subsystem, shall be capable of pulling with at least 85 percent of the force that can be exerted bare-handed on a half-inch nylon halyard.

  These tasks shall be performed with the subsystem wet and dry.

Comfort

Cold Insulation

- The hand/wrist protection subsystem shall maintain the hand at a temperature no less than 15°C (59°F) when exposed for 30 minutes to the ambient air at -23°C (-9.4°F) and a wind-chill factor of -50° C (-58° F).

Liquid Penetration - When a firefighter exerts a strong grip on an object while wearing a hand/wrist protection subsystem with a wet outer layer, a penetrating water pressure is developed. Under this condition the maximum water pressure is 27.6 kilo pascals (4 psi) which is equivalent to the maximum grip pressure. Thus, the criteria for liquid penetration through the exterior surface of the subsystem shall be the following:

- The hand/wrist protection subsystem shall prevent liquids from entering freely at, or above the wrist, and
- The hand/wrist protection subsystem shall withstand an external water pressure of 27.6 kilo pascals (4 psi) for one minute without any traces of visible leakage or seepage on the inner surfaces
- After being immersed in water for 30 seconds the weight of the hand/wrist protection subsystem shall not increase more than 5% of original weight
- The subsystem shall absorb hand perspiration so that it shall not feel uncomfortable.

Weight

- The hand/wrist protection subsystem shall weigh a maximum of 115 gm (4 oz.) per hand for a 95th percentile firefighter.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

Fit and Retention - Sizing, or fit, has a very strong bearing on dexterity and comfort. A system which fits improperly diminishes a firefighter's capability to pick up objects and manipulate controls or dials, etc.

Thus, the following criteria is established:

- The hand/wrist protection subsystem shall be available in at least three different sizes to cover the range of individuals for the 5th to the 95th percentile firefighter
- The hand/wrist protection subsystem shall be retained on the hand when a firefighter throws debris out of the way.

Service/Other

Maintainability - These requirements are given on Page 2/4-11.

Reliability - These requirements are given on Page 2/4-11.

Durability - These requirements are given on Page 2/4-11.

Donning/Doffing

- The hand/wrist protection subsystem must be capable of being donned or doffed in 5 seconds.

Recognizability

- The hand/wrist protection subsystem shall be provided with retroreflective material on the backside of each of the hands to make it visible at distances up to 200 feet at night.

Dryability

- Hand/wrist protection that has been subjected to the water penetration and absorption requirements shall be capable of being dried (95% of the absorbed water removed) in either of the following ways:

  1) 3 hr of air drying at room temperature

  2) 20 min in a 95°C (203°F) oven.

Acceptance - These requirements are given on Page 2/4-12.

Compatibility

- The hand/wrist protection subsystem shall provide a compatible interface with the torso/limb protection subsystem. The interface shall be such that water, embers, or debris will not be allowed to enter into the hand/wrist protection or torso/limb protection subsystems.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

4.1.4.2 Test Methods

Protection

Impact

The hand/wrist protection subsystem shall protect against a 2 kg (4.4 lb) slab of plaster falling from a ceiling height of 4 m (13.1 feet) and landing on the back of the hand. Under these conditions there shall be no injury to the back of the hand.

A handform will incorporate transducers which record the local pressure on the hand. An impact load of 2 kg (4.4 lb) will then be dropped upon the subsystem vertically from a height of 4 m (13.1 ft), and impact pressure will be recorded. The impactor will be approximately 1 inch thick and 5 inches long. Pressure levels in excess of 68.9 kilo pascals (10 psi), which are large enough to cause bruises, will be considered a failure.

Puncture

"The hand/wrist protection subsystem should protect against the penetration of a 4 penny nail when the applied force is 45 kg (99 lb)."

Evaluation of this criterion will be accomplished on a swatch of material removed from the palm section of the subsystem and mounted in a test fixture. A 4 penny nail, also mounted in the fixture, will be forced against the swatch of material and the force during penetration recorded. Penetration of the material at a force less than 45 kg (99 lb) will be considered a failure.

Cut

"The hand/wrist protection subsystem shall not be cut through when a 45 kg (99 lb) force is applied on a sharp edge with the palm side of the subsystem."

To evaluate this criterion a swatch of material from the palm will be mounted on a mandrel and a length of sheet metal, on its edge, drawn across the swatch at a velocity of 1 km/hr (1 ft/sec). The sheet metal will be 21 gauge, its edge will be sharpened to a 60 degree angle, and a 45 kg (99 lb) force will be applied to it as it is drawn across the swatch. Complete cutting through of the fabric will be considered a material failure.

Electricity

"The subsystem shall limit the current flow to less than 3 milliamperes when there is a 2200 volt A.C. electrical potential between the subsystems' outer surface and the part of the body it is in contact with. This criterion shall be met with the outer surface of the subsystem either wet or dry.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

The stated protection shall be provided at room temperature as well as:

a) immediately after the protection subsystem has been subjected to the Class 2 and 3 thermal environments described in Table 3-1.

b) after the subsystem has achieved an equilibrium temperature of -50°C (-58°F).

The Reference 2 test method for resistance to electricity will be used except that the applied voltage shall be 2200 volts AC and the current shall not exceed 3 milliamperes. The protector shall be subjected to the thermal environments described above prior to insertion into the resistance apparatus.

Heat Protection-Fire Scene

"The hand/wrist protection subsystem shall withstand each of the thermal environments of Classes 1, 2 and 3 and subsequently meet all other requirements without any of the inner surface that contacts the hand or wrist reaching 45°C (113°F), the pain threshold".

"When subjected to the Class 4 environment the inner surfaces of the hand protection subsystem shall not exceed the Figure 3-1 temperature-time limitations".

"After being subjected to an external water pressure of 27.6 kilo pascals (4 psi) for one minute, the subsystem shall withstand the thermal environments of Class 1, 2 and 3 without resulting in steam vapor temperatures on the inside of the protector that exceed 45°C (113°F). Under Class 4 conditions and after exposure to water as described above any steam vapor temperatures present on the inside of the protector shall not exceed the Figure 3-1 temperature-time limitations."

Evaluation of the first and second criteria exposures will be accomplished in an identical manner to that of the torso/limb protection subsystem. For these exposures a material swatch from the backside of the protector will be used for testing.

The third criterion exposures will be accomplished in a manner similar to the first and second criterion exposures except that prior to subjecting the subsystems to thermal exposure it shall be subjected to an external water pressure of 27.6 kilo pascals (4 psi) for one minute.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

Heat Protection-Conduction

"When dry, the inside surface of the hand/wrist protection subsystem shall be maintained below 45°C (113°F) during and after contact of the palm side with hot objects of 510°C (950°F) for 5 seconds at grip pressures of 27.6 kilo pascals (4 psi) without degradation."

"After subjection to an external water pressure of 27.6 Kilo pascals (4 psi) for one minute, and both during and after contact of the palm side with hot objects of 510°C (950°F) for 5 seconds at grip pressures of 27.6 Kilo pascals (4 psi), any steam vapor temperatures on the inside of the protector shall be less than 45°C (113°F). The inside surface of the protector shall also be maintained below 45°C (113°F), the pain threshold".

The first requirement will be evaluated by placing an instrumented swatch from the palm of a hand/wrist protector on a mandrel and then pressing the mandrel/test item assembly on to a 510°C (950°F) surface with a force of (30 lb) which corresponds to a 27.6 kilo pascals (4 psi) grip pressure for a 95th percentile firefighter. The protector will be instrumented with thermocouples attached to the inner surfaces of the swatch such that they tend to be pressed between it and the mandrel. The fail criterion is any indication of temperature above 45°C (113°F).

The second requirement can be evaluated by an extension of the previous method. In this instance, however, the mandrel will have a series of small, evenly spaced holes incorporated into it to allow the escape of steam vapors. Thermocouples will be placed in these passages so that when the glove swatch of the mandrel/test item assembly is pressed on to the 510° (950°F) hot surface, the thermocouples will measure the temperature of the vapors present in the passages. Before subjecting the protector to the combined effects of heat and pressure, however, the outer surface of the subsystem shall be exposed to an external water pressure of 27.6 kilo pascals (4 psi) for one minute. The failure criterion for the test is any indication of steam vapor temperatures above 45°C (113°F), the pain threshold.

Flame Resistance

"The hand/wrist protection subsystem shall not ignite, burn, char, melt or shrivel or otherwise degrade when exposed to 650°C (1200°F) flame for 5 seconds."

4.1.4 Hand/Wrist Protection Subsystem (Contd)

This requirement will be evaluated using a flame impingement test with a commercially available natural gas nozzle. The nozzle would be fed with natural gas and a 320% excess air mixture to achieve the 650°C (1200°F) flame temperature.

Performance

Dexterity

"The hand/wrist protection subsystem shall allow the firefighter to perform the Bennett Dexterity Test, while wearing the subsystem either wet and dry, at a time increase of 30% over the baseline (bare-handed) time."

The Reference 8 test method will be used for evaluating the subsystem both in dry and wet states. Time periods greater than 4 minutes shall be cause for classifying the subsystem a failure.

Grip

"The firefighter, wearing the hand/wrist protection subsystem, shall be capable of pulling with at least 85% of the force that can be exerted bare handed on a 1/2 in. nylon halyard. These tasks shall be performed with the subsystem wet and dry."

To assess grip the following test will be performed:

- A firefighter wearing the hand protection subsystem shall pull on a 1/2 in. nylon rope (with both hands). One end of the rope shall be free and the other shall be tied to a scale. This test shall be run with the protector first dry and then wet.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

Comfort

Cold Insulation

"The hand/wrist protection subsystem shall maintain the hand at a temperature no less than 15°C (59°F) when exposed for 30 minutes to the ambient air at -23°C (-9.4°F) and a wind-chill factor of -50° C (-58° F)."

To test the hand/wrist protection subsystem's ability to maintain comfort in a cold environment the subsystem will be placed on a mannequin's hand, and placed into an environmental chamber which is maintained at a temperature adjusted for the required condition. The inside back surface temperature of the subsystem shall be recorded for a period of 15 minutes. During this time a sensible heat load shall be emitted by the mannequin's hand. This may be accomplished with a recirculating hot water loop located external to the environmental chamber which supplies heat to the mannequin's hand. Under these conditions the allowable backside surface (inside) temperature of the subsystem shall be a minimum of 15°C (59°F).

Liquid Penetration

"The hand/wrist protection subsystem shall prevent liquids from entering freely at, or above the wrist, and

The hand/wrist protection subsystem shall withstand an external water pressure of 27.6 kilo pascals (4 psi) for one minute without any traces of visible leakage or seepage on the inner surfaces."

"After being immersed in water for 30 seconds the weight of the hand/wrist protection subsystem shall not increase more than 5% of original weight"

"The subsystem shall absorb hand perspiration so that it shall not feel uncomfortable."

A hand/wrist protection subsystem will be mounted on a handform and placed into a chamber which can be pressurized to 27.6 Kilo pascals (4 psi) filled with water.

Weight

"The hand/wrist protection subsystem shall weigh a maximum of 115 gm (4 oz.) per hand for a 95th percentile firefighter."

The weight of the hand/wrist protection subsystem shall be determined using a scale of the required accuracy.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

Fit or Size

"The hand/wrist protection subsystem shall be available in at least three different sizes to cover the range of individuals for the 5th to the 95th percentile firefighter."

"The hand/wrist protection subsystem shall be retained on the hand when a firefighter throws debris out of the way."

There are two tests required to establish whether the hand/wrist protection subsystem fits properly. The first test is a measurement test. The subsystem shall be pulled over a last made to proper hand sizes and checked to insure that the dimensions conform to those established as a proper fit. The second test is the successful completion of both the dexterity and grip tests. If the hand/wrist protection subsystem measures correctly and it passes dexterity and grip tests, then it can be assumed to fit properly.

Service/Other

Maintainability

"Subsystem maintenance shall be capable of being performed by firefighters at the fire station. If any process used requires curing, such as for adhesives or waterproofing, the curing shall be completely effective after 6 hours at room temperature."

Maintainability can be tested by conducting a field evaluation of several dozen hand protection subsystems at busy metropolitan fire houses over a period of six months. As maintenance will be limited to cleaning, drying, and the repair of small cuts and punctures, maintainability will have to be evaluated from logs kept by the firefighters.

Reliability and Durability

"The subsystem shall, at a minimum, satisfy all of the protection, performance, comfort, and service criteria pertinent to it for a length of time equal to its' service life."

"The subsystem shall be durable enough to provide service (as defined above) with a busy metropolitan fire company for a minimum time period of 6 months."

Subsystems will be subjected to cycles of water, heat and abrasion. Following exposure to the various environmental cycles the subsystem will be evaluated for retention of its original properties as far as:

- dexterity
- flame resistance
- thermal energy penetration

4.1.4 Hand/Wrist Protection Subsystem (Contd)

- cut protection and puncture protection
- electrical protection.

In addition, these will be supplemented by 6 months of field evaluation at a busy metropolitan fire house.

Don/Doff

"The hand/wrist protection subsystem must be capable of being donned or doffed in 5 seconds."

This requirement will be evaluated by volunteer subjects.

Recognizability

"The hand/wrist protection subsystem shall be provided with retroreflective material on the backside of each of the hands to make it visible at distances up to 200 feet at night."

This requirement will be checked by measurements of the retroreflective surfaces. The reflectivity shall be evaluated by subjecting the subsystem to the glare of automotive headlamps (on a dark night) at a distance of 200 feet. Under these conditions the subsystem markings shall be visible to an individual with 40/40 vision in one or both eyes (with or without glasses).

Dryability

"Hand/wrist protection that has been subjected to the water penetration and absorption requirements shall be capable of being dried (95% of the absorbed water removed) in either of the following ways:

1) 3 hr of air drying at room temperature

2) 20 min in a 95°C (203°F) oven."

To perform this test the hand/wrist protection subsystem will be soaked in water (inside and out) for a period of 10 seconds. It should then be allowed to drip dry at room temperatures for three minutes before being dried as follows:

a) placed in an oven preheated to and then maintained at 95°C (203°F). The subsystem shall remain in the oven for 20 minutes. At the end of this time the subsystem shall be removed and weighed, or

b) placed in an environmental chamber at 15°C (59°F) and 70% RH for a 3-hour period. At the end of this time the subsystem should be removed and then weighed.

4.1.4 Hand/Wrist Protection Subsystem (Contd)

Acceptance

"The overall characteristics of the subsystem shall be acceptable to the firefighter and promote a desire to use the protection subsystem."

A representative group of firefighters shall be used for the evaluation of acceptance. If the majority agree that the subsystem is acceptable then the subsystem can be considered to be acceptable.

Compatibility

"The hand/wrist protection subsystem shall provide a compatible interface with the torso/limb protection subsystem. The interface shall be such that water, embers, or debris will not be allowed to enter into the hand/wrist protection or torso/limb protection subsystems."

To evaluate the ability of the hand/wrist protection subsystem to meet this requirement it will be tested in conjunction with the torso/limb subsystem (or at least the interfacing portion of the latter). The subsystem and the interfacing portion of the torso/limb subsystem shall be worn by either a mannequin or a firefighter. Water from a hose shall be played upon the ensemble for 5 minutes. During this time the hand shall be elevated above the head for one-half of the test time. At the end of this period the water flow shall be stopped, the outside surfaces dried with a towel, and the hand/wrist protection subsystem removed from the wearer. There should be no evidence of water penetration into it or up into the torso/limb subsystem.

REFERENCES FOR SECTION 4.1.4

1. Manual of Directions Hand-Tool Dexterity Test - 1965 Revision, George K. Bennett, The Psychological Corp., N.Y.

2. Coletta, G.C., Arons, I.J. et al., "The Development of Criteria for Firefighters Gloves," A.D. Little, Inc. Feb. 1976

4.1.5 Foot/Ankle Protection Subsystem

The firefighters' feet must be protected from many hazards at the fireground. These include: water, heat, fire, embers, protruding nails, broken glass, wood splinters, and sharp cutting edges. Feet may be struck by falling objects such as bricks and plaster and by accidentally dropped equipment. The firefighter is required to climb stairs and ladders, step over debris, crawl, stoop and kneel, often under slippery conditions. He must have secure footing when advancing a line, when gaining entry into an involved structure, and when performing a search and rescue. Also, the firefighter must not slip when stepping on or off the apparatus and when performing routine chores in the fire station. The foot/ankle protection subsystem must be comfortable, durable, well-fitting, provide good ankle and arch support for those who want it, and be easily donned.

4.1.5.1 Requirements

Protection Criteria

Impact

a) Dynamic Impact - The most common objects that may impact the foot are loose bricks, rubble, glass, wood brands and accidentally dropped equipment such as a compressed-air tank or a hose butt. The most severe of these would be the compressed air tank. Therefore, the impact criterion for the foot shall be:

- The toe shall not be bruised by an air bottle 10 kg (22 lb) falling 1.5 m (4.9 ft)

It is unlikely that the air bottle would hit the instep, but a hose butt or nozzle may; therefore, the impact criterion for the instep shall be:

- The instep shall not be bruised by dropping a hose nozzle or a suction-hose butt weighing 4.5 kg (9.9 lb), 1.2m (3.9 ft).

b) Compression - In addition to the aforementioned criterion there is also the possibility of a firefighter's toe being run over by a fire apparatus. Therefore, the compression criterion requirement for the toe area shall be:

- The toe shall not be bruised by a fire apparatus (weighing up to 16,000 kg (35,200 lb)) running over it

Puncture - Stepping on nails is the most common puncture hazard that is encountered in fighting fires. This usually occurs during the overhaul phase when surrounding wood has been pulled down. The exposed nails may still be embedded in a piece of wood so that

4.1.5 Foot/Ankle Protection Subsystem (Contd)

they are supported in an upright position. Based on these occurrences the foot/ankle protection subsystem must provide the following puncture protection:

- The firefighter shall be able to step on a 4 penny nail without the point penetrating the foot. The entire bottom of the foot, including arch and side areas, shall be so protected.

Cut - Protruding nails, falling glass and edges of sheet metal are typical hazards of the fireground. In addition, cuts may be incurred by accidental contact with sharp edged tools. Of these, the most severe and potentially dangerous tool is the power saw. Boots which incorporate steel toe protection have prevented injuries when a toe has contacted an operating saw blade. Even though a saw could cut through a toe cap, the increased noise and vibration would alert the operator before permanent foot damage occurs. Based on the above hazards the following cut protection shall be provided by the foot/ankle protection subsystem:

- The toe shall not be cut through by the rotating blade of a firefighters' hand-held power saw, when the saw is held against the toe by its own weight for 5 seconds
- The instep shall not be cut through by falling broken glass
- All other areas of the foot shall not be cut through by the edge of a protruding piece of sheet metal when the edge is struck at a walking gait.

Flame - These requirements are given on Page 2/4-2.

Heat - The hazard of heat strikes at the firefighters' feet primarily through radiation and conduction. Radiant heat energy reaches him from nearby flames, while contact with hot surfaces and hot water is the most important mode of heat conduction.

Fire Scene Thermal Environment - The thermal environment encountered by the firefighter may be characterized by four combinations of exposure time, temperature, and flux, shown in Table 3-1.

Based on these considerations the following criteria are required for radiant heat protection:

- The foot/ankle protection subsystem shall withstand each of the radiated heat environments of Classes 1, 2 and 3 and subsequently meet all other requirements without any of the inner surfaces of the subsystem reaching 45°C (113°F), the pain threshold.

4.1.5 Foot/Ankle Protection Subsystem (Contd)

- When subjected to the Class 4 environment the inner surface of the foot/ankle protection subsystem shall not exceed the Figure 3-1 temperature-time limitations.

- After soaking the external portion of the protector for 5 minutes in water, the subsystem shall withstand the Class 1, 2 and 3 thermal environments without resulting in steam vapor temperatures, on the inside, in excess of 45°C (113°F). Under Class 4 conditions any steam vapor temperature present on the inside shall not exceed the Figure 1 temperature-time limitations.

Conduction - Conductive heat requirements are as follows:

- The firefighter shall be able to stand on a metal surface at 121°C (250°F) for 10 minutes without any inner surface of the foot/ankle protection subsystem reaching 45°C (113°F), the pain threshold, when dry.

- The firefighter shall be able to stand in 82°C (180°F) water, 3.8 cm (1½-in.) deep, for 10 minutes, without any inner surface of the foot/ankle protection subsystem reaching 45°C (113°F), the pain threshold.

- After soaking the external surfaces of the protector the firefighter shall be able to stand on a metal surface at 121°C (250°F) for 10 minutes without any steam vapor temperatures on the inside of the protector reaching 45°C (113°F). The inside surfaces of the protector shall also be maintained below 45°C (113°F), the pain threshold.

Electricity - These requirements are given on Page 2/4-2.

Performance Criteria

Mobility - The firefighters' protective equipment may cause some decrease in mobility compared to wearing street clothes, but this decrease must be kept to a minimum. The following criterion provides a job-related physiological basis for assessing foot/ankle protection subsystem mobility:

4.1.5 Foot/Ankle Protection Subsystem (Contd)

- When wearing the foot/ankle protection subsystem, the firefighter shall be able to climb a flight of stairs at an energy expenditure not more than 10% greater than when wearing street shoes.

Grip and Traction - Traction is extremely important to the firefighter because many accidents start with a slip and result in sprains, strains and broken bones. Good traction must be provided on both wet and icy surfaces as well as dry surfaces. The following criteria will insure that the foot/ankle protection subsystem provides a safe gripping surface:

- The firefighters' foot/ankle protection subsystem shall provide the same traction on dry surfaces as that obtained with Vibram-soled hiking boots.
- The level of traction on wet surfaces shall not be less than 90% of that provided on dry surfaces.
- The subsystem shall not mar floors while providing traction.

Comfort Criteria

Cold Insulation - Winter duty is considered the most severe environment for footwear comfort. In extreme weather, cases of frostbite are not uncommon as the firefighter may be forced to work in snow and sleet, or may need to wait out-of-doors before entering an involved building. As there is no comparable danger in summertime, it is the winter environment that leads to the following cold insulation criteria:

- The wearer shall be able to remain in 20 cm (7.9 in.) deep snow at -23°C (-9.4°F) for 30 minutes without feeling discomfort due to cold feet. The temperature of the inner surface shall not drop below 15°C (59°F).

Water Penetration and Absorption - At a multiple alarm fire during the extinguishment phase, the firefighter may encounter water on the sidewalks, water streaming down staircases, water dripping through ceilings, or water spewing from broken pipes or hoses. In these cases water depth is usually minimal. On the fire floor the engine company may be required to work in 2.5 cm (1 inch) or so of water.

The floors below the fire can become as wet as those on the fire floor, and may accumulate water to 5 cm (2 in.) or 7.6 cm (3 in.), while in the basement the water can

4.1.5 Foot/Ankle Protection Subsystem (Contd)

frequently rise to higher levels. Observations made in the field (Reference 2) show, however, that exposure to water levels above 20 cm (7.9 in.) is an accasional occurrence. It should be noted that at times the firefighter may be standing in liquids or liquid solutions other than those consisting primarily of water alone. Examples of these include solutions containing oil, gasoline, pesticides, etc. In the light of the above considerations the following liquid penetration criteria are based on the most likely occurrences faced by firefighters:

- The firefighter shall be able to stand in 20 cm (7.9 in.) deep water for 30 minutes without water penetrating through the foot/ankle protection subsystem. In addition, the interface between the foot and leg protectors shall prevent water entry.

Weight - The weight of the foot/ankle protection subsystem must be as low as possible to provide the least encumbrance to the wearer, and to minimize fatigue when performing his tasks. Thus, the following criterion is required:

- Total weight of the foot/ankle protection subsystem shall not exceed 1.8 kg (4 lb) maximum, for both feet, for the size 12 foot of a 95th percentile firefighter.

Fit - To be effective the foot/ankle protection subsystem should fit well. To this end, the following criterion is required:

- Foot/ankle protection subsystems shall be available in the same size ranges as are available for street shoes, namely, full and half sizes and a range of widths.

Support - To minimize fatigue and provide comfort, the loads which are transferred to the feet must be distributed over the complete foot area. To achieve this goal, the so-called ladder shank, which distributes the concentrated load when working on ladders, is required. Alsc, arch and ankle supports may be provided as an additional option to minimize fatigue. The support criteria are as follows:

- The foot/ankle protection subsystem shall incorporate a ladder shank.

Service/Other Criteria

Maintainability - These requirements are given on Page 2/4-11.

Reliability - These requirements are given on Page 2/4-11.

Durability - These requirements are given on Page 2/4-11.

4.1.5 Foot/Ankle Protection Subsystem (Contd)

Donning/Doffing

- If the foot/ankle protection subsystem is donned at every response, it must be capable of being donned on both feet and ready for use in 8 seconds. The foot/ankle protection subsystem must be capable of being rapidly removed from an injured or unconscious man.

Recognizability - To aid in identification of firefighters when visibility is impaired by smoke or darkness, reflectorized material shall be incorporated into the foot/ankle protection subsystem. The following requirement will assure this property:

- The foot/ankle protection subsystem shall be provided with retroreflective surfaces areas to make it visible at distances up to 200 feet at night.

Dryability - There is a possibility that the inside of a firefighters' foot/ankle protection subsystem will become soaked with perspiration. The foot/ankle protection subsystem can also be wet if water beyond the depth of the waterproofness is encountered. For these reasons the foot/ankle protection subsystem must be capable of being dried in a reasonable time, e.g., the normal time between shifts. Also, it must be able to withstand repeated dryout cycles for the service life, as covered by the following criteria:

- A foot/ankle protection subsystem that has been soaked through by being completely immersed in water for 5 minutes shall not increase in weight by more than 5% and shall be capable of being dried (75% of the absorbed water removed) in either of the following ways:

  1) 6 hr of air drying at room temperature

  2) 1 hr in a 95°C (203°F) oven.

Acceptance - These requirements are covered on Page 2/4-12.

Compatibility - To assure the effectiveness of the entire firefighters' ensemble, it is necessary that all the component items function well together. To this end the following criterion is necessary:

- The foot/ankle protection subsystem shall incorporate means to insure that a compatible interface exists between it and the leg protector, and a water tight seal achieved.

4.1.5 Foot/Ankle Protection Subsystem (Contd)

4.1.5.2 Test Methods

Protection Criteria

Impact

"The toe shall not be bruised by an air bottle 10 kg (22 lbs.) dropping 1.5 m (4.9 ft)."

"The instep shall not be bruised by dropping a hose nozzle or a suction hose butt weighing 4.5 kg (9.9 lb), 1.2 m (3.9 ft)."

To satisfy the toe bruise criterion the impact tests defined in the American National Standards Institute Z41.1-1967 (R1972) Standard for Men's Safety Toe Footwear (Reference 1) are to be utilized with the following changes:

(a) The impact mass is increased to 34 kg (74.8 lb) ±0.23 kg (.51 lb).

(b) The drop height for the impact mass is to be adjusted to a nominal value of 44.7cm (17.6 inches) in order to achieve the required impact energy of 15 kg-m (108 ft-lb).

The ANSI Z41.1 1.17 cm (0.50 inch) minimum clearance during impact shall be maintained.

For metatarsal impact, the ANSI Z41.2-1976 standard (Reference 1) is to be utilized with the following changes:

The drop height for the impact mass is to be adjusted to a nominal value of 24.4 cm (9.6 inches) in order to achieve the required impact energy of 5.4 kg-m (39 ft-lbs).

Compression

"The toe shall not be bruised by a fire apparatus running over it."

This requirement will be tested by the ANSI Z41.1 standard toe compression requirement, with an increased applied load of 1350 kg (3000 lbs).

Puncture

"The firefighter shall be able to step on a 4 penny nail without the point penetrating the foot. The entire bottom of the foot, including the arch and side areas, shall be so protected."

C-2

4.1.5 Foot/Ankle Protection Subsystem (Contd)

The proposed ANSI Z41.5 1977 Standard will be used as the basis for evaluating sole, arch and side area puncture resistance with the modification that the entire bottom of foot, including arch and side areas, be protected.

The protective midsole, arch, and side areas would have to withstand a force of not less than 135 kg (297 lb) when penetrated with a 4 penny common nail penetrator.

The load is applied at a required rate of 5 cm/minute (2 inches per minute) ± 4%. The load at penetration will be recorded and values less than 135 kg (297 lb) considered a failure.

Toe Cut

"Toe shall not be cut through by the rotating blade of a firefighter's hand-held power saw when held against the toe by its own weight for 5 seconds."

This unique requirement is straightforward and should not present any problems in developing an appropriate detailed test procedure. Attention will have to be given to putting controls on the sharpness of the saw blade (perhaps using a fresh blade) and specifying the alignment of the saw blade to the steel toe cap of the boot. It should duplicate the striking angle and direction that would be encountered when the fireman had cut through some material but inadvertently continued the cutting stroke down toward the foot.

Instep Cut

"The instep shall not be cut through by falling broken glass."

This test can be performed by using the universal shoe test machine designed and fabricated by Dayton T. Brown, Inc. The machine is normally used to perform the toe impact, toe compression, metatarsal impact and sole penetration tests. It would require only minor modification to be used for a drop test on the instep (metatarsal) with the edge of plate glass as a contacting material.

The test method would be to set the test boot on the base of the machine, raise the drop mass (with a piece of plate glass positioned normal to the long axis of the boot) to a height necessary to achieve the required impact energy. This test would require the placing of a last within the boot to simulate the resistance of a foot.

4.1.5 Foot/Ankle Protection Subsystem (Contd)

Cut Resistance

"All other areas of the foot shall not be cut through by the edge of a protruding piece of sheet metal, such as used to board up abandoned buildings, when the edge is struck at a walking gait."

To evaluate this criterion swatches of material from the other various areas of the subsystem will be mounted on a mandrel and a length of sheet metal, on its edge, drawn across them at a velocity of 6 km/hr (3.7 mph). The sheet metal will be 21 gauge, its edge will be sharpened to a 60 degree angle, and a 10 kg (22 lb) force will be applied to it as it is drawn across the swatches. Testing shall be conducted after Class 2 and 3 exposures.

Complete cutting through of the subsystem material will be considered a material failure.

Flame Resistance

"The foot protection shall not ignite, burn, char, melt or shrivel or otherwise degrade when exposed to a 650°C (1200°F) flame for 5 seconds."

This requirement can be met through a flame impingement test where a commercially available natural gas nozzle is employed. The nozzle would be fed with natural gas and a 320% excess air mixture in order to achieve the 650°C (1200°F) flame temperature.

Heat Resistance

A. "The foot protection shall withstand each of the radiated heat environments of Classes 1, 2 and 3 without any of the inner surface reaching 450°C (113°F) (pain threshold).

B. "When subjected to the Class 4 environment the inner surface of the foot protection shall not exceed the Figure 3-1 temperature-time limitations."

C. "After soaking the external portion of the protector for 5 minutes in water, the subsystem shall withstand the Class 1, 2 and 3 thermal environments without resulting in steam vapor temperatures, on the inside, in excess of 45°C (113°F). Under Class 4 conditions any steam vapor temperature present on the inside shall not exceed the Figure 3-1 temperature-time limitations."

4.1.5 Foot/Ankle Protection Subsystem (Contd)

D. "The firefighter shall be able to stand on a hot surface of 121°C (250°F) for 10 minutes without any inner surface of the boot reaching 45°C (113°F) (pain threshold), when dry."

E. "The firefighter shall be able to stand in 82°C (180°F) water, 3.8 cm (1½ in.) deep, for 10 minutes without any inner surface of the boot reaching 45°C (113°F) (pain threshold)."

F. "After soaking the external surfaces of the protector the firefighter shall be able to stand on a metal surface at 121°C (250°F) for 10 minutes without any steam vapor temperatures on the inside surfaces of the protector reaching 45°C (113°F). The inside surfaces of the protector shall also be maintained below 45°C (113°F), the pain threshold."

The "A" and "B" criteria exposures can be performed in a manner similar to that detailed in Method 505 of MIL-STD-810 for heat build-up with appropriate modifications to accomodate the desired air temperature, radiant flux and exposure times. During these exposures, a mandrel simulating a foot, ankle, and calf will be inserted into the boot to prevent ambient airflow. The areas of the thermocouple exposed to the footform will be insulated. The inner surface of the boot will be instrumented with five thermocouple junctions in the following areas:

a) insole ball area
b) insole heel area
c) upper vamp (over the ball area)
d) side ankle area
e) rear upper area

The conditions will be established in the chamber first, and then the boot together with the mandrel and the temperature transducers will be placed in the chamber for the required exposure period. Temperatures will be continually recorded during the exposure periods.

The "C" criterion exposures are evaluated by an extension of the previous methods. In this instance, however, the mandrel simulating the foot, ankle and calf will have a series of small evenly spaced holes incorporated into it to allow the escape of steam vapors from the inside of the protector. Thermocouples will be placed in the holes so that they will measure the steam vapor temperatures in the passages. Before subjecting the subsystem to the thermal exposures, however, the outer surface of the protector shall be soaked in water for 5 minutes.

4.1.5 Foot/Ankle Protection Subsystem (Contd)

The "D" and "E" criteria would be accomplished in a straightforward manner using a temperature controlled "hot plate" type surface and a temperature controlled bath. The temperature monitoring equipment would be the same as for criteria A & B.

The "F" criterion exposure will be evaluated in much the same manner as criteria "D" and "E" except that the mandrel and thermocouples used will be as given for criterion "C".

Electricity

"The subsystem shall limit the current flow to less than 3 milliamperes when there is a 2200 volt A.C. electrical potential between the subsystem's outer surface and the part of the body it is in contact with. This criterion shall be met with the outer surface of the subsystem either wet or dry.

The stated protection shall be provided at room temperature as well as:

a) immediately after the protection subsystem has been subjected to the class 2 and 3 thermal environments described in Table 3-1.

b) after the subsystem has achieved an equilibrium temperature of -50°C (-58°F)."

This requirement will be tested using the ANSI Z41.4 1976 Standard for Electrical Hazard Safety-Toe Footwear. The subsystem shall be subjected to the thermal environments described above prior to this electrical test. For evaluation of a wet subsystem the protector shall be wet by standing it in 20 cm (7.9 in.) deep water for 30 minutes, shaken dry and then subjected to the electrical voltage. Current flows in excess of 3 milliamperes shall be considered a failure.

Performance Criterion

Grip and Traction

"The firefighter's foot/ankle protection subsystem shall provide the same traction on dry surfaces as that obtained with Vibram soled hiking boots."

"The level of traction on wet surfaces shall not be less than 90% of that provided on dry surfaces."

"The subsystem shall not mar floors while providing traction."

4.1.5 Foot/Ankle Protection Subsystem (Cont)

Traction tests shall be performed using a spring-force tester to measure slippage forces. A volunteer shall grasp a 1/2-inch halyard attached to a spring-force tester which is, in turn, attached to a rigid support. By leaning backwards, the force at which he slips can be measured. The test shall be done on wet and dry surfaces wearing the test item, and the results compared to those obtained wearing Vibram-soled hiking boots.[4]

Comfort Criteria

Water Penetration and Absorption

"The wearer shall be able to stand in 20 cm (7.9 in.) deep water for 30 minutes without water penetrating through the foot protection system. In addition, the interface between the foot and leg protectors shall prevent water entry."

The method to be used in verifying this requirement is straightforward. The boot is fitted with a simulated flexible foot-form around which a blotting paper has been applied. The weighted boot and footform are then lowered into room temperature water and allowed to stand for the 30 minute exposure period in a normal upright position. During this time, the foot form shall be flexed to simulate boot flexing during a normal 3 mph walking gait. At the conclusion of the period the blotting paper is examined for any evidence of seepage, which would be caused for rejection. If there is no seepage at the end of the 30 minute exposure period, the procedure shall be repeated. It shall be repeated a total of 32 times or until evidence of seepage occurs, whichever is less.

Weight

"Total weight of the foot protection subsystem shall not exceed 1.8 kg (4 lb) maximum for both feet, for the size 12 foot of a 95th percentile firefighter.

This also is a straightforward requirement. The pair of boots should be weighed on a scale capable of reading accurately to at least ± 28 gm (± 1.0 ounce).

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[4] Vibram is the manufacturer of oil resistant, non-marking, flexible, long wearing, high-grip soles and heels which are used on hiking boots and work shoes. R

4.1.5 Foot/Ankle Protection Subsystem (Contd)

Service/Other Criteria

Maintainability

"The subsystems maintenance shall be capable of being performed by firefighters at the fire station. If any process used requires curing, such as for adhesives or waterproofing, the curing shall be completely effective after 6 hours at room temperature.

"In station maintenance of the foot/ankle protector may be limited to areas other than the soles and heels. If a shoe repair shop is required for repair, only the standard tools and techniques used in such a shop shall be required and the repair shall be consistent with present practice on conventional boots."

Evaluation of this requirement consists mainly of a visual examination of the boot to determine the method of construction. Those portions of the vamp and uppers that may be damaged in time, and are replaceable, should be actually replaced, using the adhesives recommended to verify the 6 hour maximum curing time allowed in accordance with the manufacturers recommended instructions.

Reliability and Durability

"The subsystem shall, at a minimum, satisfy all of the protection, performance, comfort, and service criteria pertinent to it for a length of time equal to its service life."

"The subsystem shall be durable enough to provide service (as defined above) with a busy metropolitan fire company for a minimum time period of 2 years."

For this evaluation the subsystem will be subjected to cycles of water, heat, impact and flame. Following exposure to these environmental cycles the subsystem will be evaluated for retention of its original properties in the areas of:

- impact, puncture and cut resistance
- flame and heat resistance
- electrical protection

In addition, these tests will be supplemented by a one year field evaluation at a busy metropolitan fire house. Attention will be given to subjecting a sufficient number of samples to this evaluation so that the subsystem can be re-evaluated with a reasonable level of statistical significance.

4.1.5 Foot/Ankle Protection Subsystem (Contd)

Donning/Doffing

"If the foot/ankle protection subsystem is donned at every response, it must be capable of being donned on both feet and ready for use in 8 seconds. The foot/ankle protection subsystem must be capable of being rapidly removed from an unconscious man."

This requirement will be evaluated by volunteer subjects.

Recognizability

"Foot protection shall be provided with retroreflective surfaces to make it visible at distances up to 200 feet at night."

This requirement will be checked visually. The reflective surfaces shall be evaluated by subjecting the subsystem to the glare of automotive headlamps (on a dark night) at a distance of 200 feet. Under these conditions, the subsystem markings shall be visible to an individual with 40/40 vision in one or both eyes (with or without glasses).

Dryability

"A foot/ankle protection subsystem that has been soaked through by being completely immersed in water for 5 minutes shall not increase in weight by more than 5% and shall be capable of being dried (75% of the absorbed water removed) in either of the following ways:

1) 6 hr of air drying at room temperature
2) 1 hr in a 95°C (203°F) oven."

To perform this test the subsystem, after having been soaked as described above, should be allowed to drip dry at room temperature for three minutes before being weighed.

Under these conditions the weight shall not be greater than 5% of its original value. The subsystem shall then be dried as follows:

a) placed in an environmental chamber at 15°C (59°F) and 70% RH for a 6 hr period. At the end of this time the subsystem should be removed and then weighed, or

b) placed in an oven preheated to and then maintained at 95°C (203°F). The subsystem shall remain in the oven for 1 hour. At the end of this time the subsystem shall be removed and weighed.

Inability to remove 75% of the absorbed water shall be considered a subsystem failure.

4.1.5 Foot/Ankle Protection Subsystem (Contd)

Acceptance

"The overall characteristics of the subsystem shall be acceptable to the firefighter and promote a desire to use the protection subsystem."

A representative group of firefighters shall be used for the evaluation of acceptance. If the majority agree that the subsystem is acceptable then the subsystem can be so considered.

Compatibility

"The foot/ankle protection subsystem shall incorporate means to insure that a compatible interface exists between it and the leg protector, and a water tight seal achieved."

To evaluate the ability of the foot protector to meet this requirement it will be tested in conjunction with the torso/limb subsystem (or at least the interfacing portion of the latter). The subsystem and the interfacing portion of the torso/limb subsystem shall be worn by either a mannequin or a firefighter. Water from a hose shall be played upon the ensemble for 5 minutes. At the end of this period the water flow shall be stopped, the outside surfaces dried with a towel, and the foot/ankle protection subsystem removed from the wearer. There should be no evidence of water penetration into the foot/ankle protector.

REFERENCES FOR SECTION 4.1.5

1. American National Standard - ANS1Z41-1967, "Standard for Men's Safety-Toe Footwear"

4.2 SELF CONTAINED BREATHING SYSTEM

The function of the Self Contained Breathing System is to protect the firefighter from the effects of toxic substances on the pulmonary system and to enable work in low oxygen concentrations. In addition, the system must protect the firefighter from a variety of hazards to the nose, mouth, and eyes. It must also provide the firefighter with a sufficient supply of breathing gas to match metabolic needs. In providing these properties the system must be comfortable and should not encumber the firefighter.

4.2.1 Requirements

Protection Criteria[5]

Smoke and Toxic Substances - Smoke is both toxic and irritating to an individuals respiratory system. Field analyses show that the degree of toxicity is usually a combined result of the material burning, the intensity of the heat, and the time spent at the fire.

At the fire scene it is common for the firefighter to experience a watering of the eyes, coughing, running nose and spitting up of mucus, all caused by atmospheric irritants. These irritants can take the form of:

a) Aerosols which are droplets or solids suspended in air commonly found in fog and mists.

b) Gaseous contaminants whose presence in small quantities might not only cause irritation but possibly sickness and even death. Examples of this are ammonia, carbon monoxide, sulfur dioxide, etc.

c) Particulate matter whose presence in the air can cause, depending upon their size, irritation or lung disease.

To function safely in an environment containing contaminants as described, the firefighter must wear a breathing apparatus as a precautionary measure. Therefore, the following criterion is adopted:

- The system must protect the firefighter from smoke and contaminants, and provide fresh breathing gas.

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[5]Since the system, by definition (above), provides safeguards for the firefighter both from the effects of toxic substances and low oxygen concentrations, and from a variety of hazards to the nose, mouth and eyes, applicable criteria from the face/eye protection subsystem are included (i.e., impact, puncture, cut, and electricity).

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

Impact - Flying and falling objects such as masonry rubble, roofing stones and shingles, wooden splinters, nails and glass shards can all cause impact injuries to the firefighters face and eyes. Impact protection particularly must be provided from small objects which might pierce the eye. Large objects may cause damage to the face and eye areas but seem to be less likely to cause permanent eye damage. Also if impact protection were required against large objects the resultant protective apparatus would probably be too heavy to be practical. The following protective criteria have therefore been chosen to reflect realistic impact protection requirements:

- The facemask portion of the system shall withstand the impact of a brick falling 4 stories. There shall be no spalling or shattering of the facemask in the rearward direction, that is, toward the face. This requirement shall be met before and after the facemask has been subjected to the heat requirements of Class 1, 2 and 3 of Table 3-1. This requirement is to be met both in the stowed and deployed positions.

Puncture - The objects listed above as potential causes of impact injuries can also be considered as capable of causing punctures. Just about any sharply pointed, falling object may pose a threat to the firefighters face and eyes. In addition to pointed objects, a danger exists that objects which might normally not puncture the facemask may do so if they are hot, or if the equipment itself is hot. The following requirements have taken these situations into consideration:

- These facemask portion of the system shall not be penetrated by the tip of a 4 penny nail impacting the subsystem with an energy of 1.4 Kg-m (10 ft-lb). The requirement shall be met with the nail at room temperature and also with the nail at 60°C (140°F). These requirements shall be met before and after the subsystem has been subjected to the heat requirements of Class 1, 2, and 3 of Table 3-1. This requirement is to be met both in the stowed and deployed positions.

Cuts and Scratches - The potential for cut and scratch damage exists whenever a sharp object strikes a glancing blow to the facemask. Resistance to cuts and scratches is needed to insure service durability as well as to protect the firefighter.

- The outer surface of the facemask shall not be cut nor suffer any surface impairment by the sharp edge of a metal venetian blind being drawn against it.

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

- The outer surface of the facemask shall not suffer any impairment after being rubbed with a dirty, sandy firefighter's glove at moderate finger tip pressure over its width for 5 cycles.
- The above two requirements shall be met before and after the facemask has been subjected to the heat requirements of Class 1, 2 and 3 of Table 3-1.

Heat - Heat reaches the system primarily through radiation, although conduction via hot air plays a role.

The characteristics fire scene thermal environments encountered by the firefighter are given in Table 3-1.

Based on these considerations the following design criteria are required for heat protection:

- The facemask portion of the system shall withstand the thermal environments of Classes 1, 2, and 3 without any visible distortion and subsequently meet all other requirements of this section. Class 1 shall be imposed separately, while Class 2 and 3 shall be imposed sequentially with Class 2 first followed by Class 3. Under these conditions the inside surfaces of the facemask in contact with the firefighter's face shall not exceed 45°C (113°F).
- When subjected to the Class 4 environment the facemask shall remain intact. Under these conditions the inside surface temperatures of the protector in contact with the firefighter's face may not exceed the Figure 3-1 temperature-time limitations.

Electricity - These requirements are given on Page 2/4-2.

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

Flame - The system may see flame from a falling brand, or burning debris as the firefighter is performing a search and rescue. For these situations the following criterion is established:

- The system, including the face mask, backpack and interconnecting hoses, straps and other retaining devices shall not ignite, burn, char, melt or shrivel when exposed to 650° C (1200° F) flame for a 5-second period. Furthermore, the system shall not incur any changes or degrade to the point where it no longer satisfies the remaining requirements of this document.

Performance Criteria

Mobility - To be able to perform such tasks such as extinguishment, search and rescue, and overhaul, the firefighter must be able to climb stairs, walk over obstacles, stoop, kneel or crawl with as much ease and safety as possible. Toward this end, the following criterion is established:

- The firefighter, when wearing the system together with his Protective Garment System, shall be able to bend and reach at an energy expenditure no more than 10% greater than when wearing the torso protection subsystem alone. In addition, the system shall not interfere with the mobility of the firefighters arms, legs and neck as provided by the torso protection subsystem.

Visibility - The firefighter is called upon to work in environments where visibility is poor. Under these conditions the individual may be climbing stairs or walking in a debris-filled structure trying to find the way in or out, safely, or performing a search and rescue task. In such situations good visibility is necessary not only for safety but to successfully perform the tasks. Toward this end the following criteria are established:

- The face mask lenses for the eyes should be large enough so that the firefighter's peripheral field of vision is not reduced, and at a minimum it shall cover the eyes, nose, cheekbones, mouth, and temple areas.
- The face mask lens should not attenuate light nor distort images. It shall meet the optical performance standards of the American National Standards Institute Specification ANSI Z87.1 (Reference 1), latest revision
- Fog should not be allowed to form on the lenses nor should moisture condense thereon.

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

Hearing - Because of the firefighter's need for communicating at the fire ground it is mandatory that the protective equipment does not impair hearing ability. Thus the following criteria are established:

- No portion of the system shall inhibit hearing either by virtue of the noise it makes during operation or by the way it must be worn.

Speaking - The firefighter has a need to communicate at the fire ground, with victims or other firefighters. Thus, it is mandatory that the protective equipment not impair communications with the breathing system in place. Therefore, the following criterion is established:

- The system shall enable the firefighter to communicate at normal speaking voice levels with other persons at distances up to 25 ft while it is worn. The firefighter shall not be forced to remove any portion of the system to communicate.

Breathing Gas Quality - Carbon monoxide, carbon dioxide, methane and hydrocarbons, all of which could be lethal in certain concentrations are present in most fires in varying quantities. The hydrocarbon grouping, alone, could be representative of any of thousands of organic compounds, many of which could be lethal. Therefore, the danger posed to the firefighter by toxic contamination in the atmosphere at any one particular fire is dependent upon the specific contaminants, their concentrations, and the amount inspired, all of which are a function of the material burning, the temperature of the fire, and the duration of exposure.

At many fire scenes the oxygen level at the fire scene is normal, i.e., approximately 20%. However, there are conditions, usually associated with high heat, when the level of oxygen may drop lower than 15%. Low oxygen levels are accompanied by high carbon dioxide and high carbon monoxide levels. Man can work safely in an environment where the oxygen level is as low as 17% for periods from 1/2 to 1 hour. However, when levels drop below 17% he will start to suffer from hypoxia. Hypoxia will first affect vision, then cause loss of coordination, poor judgment, fatigue and, ultimately, result in dealth.

The system must therefore not only prevent the fire bred contaminants from entering into the firefighters' eyes, nose, mouth and lungs, but provide sufficient oxygen so that he may function unimpaired. Therefore, the following criteria are established:

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

- The system must provide breathing gas in the immediate vicinity of the firefighter's nose and mouth that has a minimum oxygen content of 21% (by volume) during inhalation. Immediately after exhalation this oxygen content may be as low as 18%. The carbon dioxide content on the other hand shall not exceed 1/2% (by volume) during inhalation.

- Trace amounts of gases normally found in a non-polluted ambient environment, e.g., argon, are permissible in the breathing gas. However, trace amounts of toxic substances, e.g., carbon monoxide, hydrocarbons, etc., which are by-products of combustion or which are present in the ambient environment at the fire scene, shall not be present in the breathing gas in quantities exceeding those allowed by the Compressed Gas Association for Grade f gases. A protection factor of 10,000 shall apply in those cases where the Compressed Gas Association does not specify a permissable value.

- For maximum comfort the breathing gas temperature during inhalation shall be in the range of -1.0°C (30°F) to 43°C (109°F).

- The system shall be capable of operating with a gas pressure within the breathing mask not to exceed 2.8 mm Hg (1.5 inches of H_2O) above ambient pressure. This requirement is not intended to preclude the use of multi-mode devices which permit both positive pressure and demand type operations.

Flow Rate and Duration - The duration of the Self Contained Breathing Gas System provides enough time for the firefighter to do the job and escape safely, if necessary. Results of field observations and a review of reports indicate that the firefighting operations of a busy metropolitan fire station can be grouped into three classifications:

- Typical single alarms
- Multiple alarms
- Special operations

The vast majority of single alarms to which metropolitan firefighters respond require an effort of less than 10 minutes. The duration for these common jobs need be no more than 10 minutes plus an allowance of 2 to 5 minutes for egress.

The protection factor is equal to the ratio of the concentration of the concentration in the ambient atmosphere to that inside the facepiece under conditions of use.

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

The multiple alarm or the "all hands" are those fires which usually are not brought under control in less than 15 minutes. Here the firefighter is most likely to be exposed to smoke for intervals of 15 to 30 minutes before being relieved. For this situtation a duration allowing for a maximum of 30 minutes operation with a reserve supply of at least 5 minutes for egress is required. The 30 minute duration is compatible with the firefighters' ability to work strenuously for periods of up to one half hour without being exhausted. Thus, a 35 minute system with an audible alarm set to go off after 30 minutes of operation would meet the need of the second most common demand on the system.

The single and multiple alarms previously described are associated with the most common structural fires. These are buildings of between one and six stories where the firefighter can get to the fire in a relatively short time. There are, however, certain special cases where the firefighter may have to spend considerable time in a toxic environment before reaching the fire. Examples are fires in high-rise office buildings and tunnels.

These fires, however, are infrequent occurrences, require special consideration and, therefore, should not be the determining factor for the system's duration. Except for these special situations which may require the use of more than one charge of the system, the normal needs of the firefighter can be satisfied with a system that has a 35 minute duration. Such a unit should provide 30 minutes of operating time with an additional allowance of 5 minutes for egress.

Based upon field measurements made in previous studies (Reference 2) it was found that the average maximum metabolic rate at which the typical firefighter operates is 156 Kcal/hr. The corresponding oxygen consumption rate is 2.5 liters per minute. However, it was also established during controlled tests that there are men who will on occasion consume between 2.5 and 3 liters of oxygen a minute.

On the bases given above, the following criterion is established:

- A system shall provide 2.5 liters of oxygen per minute for 35 minutes and have the capability of satisfying a peak consumption rate of 3 liters of oxygen per minute.

Water Penetration - Every firefighter faces falling water which he may encounter from an open sprinkler head, or from a nozzle stream bouncing off walls and ceilings, or even from a driving rain. This water may be ice cold or steaming hot. Under these con-

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

ditions the firefighter's face and eyes must remain dry and the system must remain unaffected by the water. The following criterion for system performance is required:

- The face mask portion of the system shall not permit dripping water from a 3 m (9.8 ft) ceiling, falling water from a 60 1/m (15.9 gpm) sprinkler head, driving water from a rainstorm or deflected nozzle stream to enter the covered face area of the firefighter regardless of the position he is in. In addition, remaining portions of the system, e.g., the backpack and the hoses, shall not absorb water, nor shall water be allowed to enter either the hoses, couplings, or the backpack.

Comfort Criteria

Weight - The weight of the system must be low as possible to provide the least burden to the wearer, and to minimize fatigue. Current systems weigh approximately 15 kg (33 lb) when fully charged and are both heavy and cumbersone.

An improved system just finding its way into use weighs about 11 kg (24.2 lb). Although this offers a significant weight reduction over the original unit, further reductions are both desirable and feasible. Therefore, the following weight is established as a target for the system:

- The weight, of the fully charged system including the mask and hoses, shall be a maximum of 7 kg (15.5 lb).

Size and Volume - To reduce the possibility of a firefighter becoming caught or trapped in doorways, on fire escapes, in windows, etc., his/her profile must be kept as small small as possible. Toward this end, the following criteria are established.

- The maximum system size should be 43 cm (17 in.) wide x 43 cm (17 in.) high x 20 cm (7.9 in.) deep. This size insures that the backpack is within the person's frontal profile and that the person's center of gravity is not significantly affected.

Fit - To be effective the system must fit well and not interfere with the firefighters' ability to reach and bend. To this end, the following criteria are required:

- The system shall be capable of being borne by the torso of a firefighter equipped with both head/ear and torso/limb protectors.
- Fit should be snug but not overly tight
- Aside from the connecting hoses to the face mask, movement of the system shall be minimized during firefighting activities.

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

Service/Other Criteria

Environmental Operating Requirements - The environment that the firefighter works in varies. Depending upon the type of fire, how, where and when it is being fought, the temperatures, pressures, humidity, etc., all vary.

For the firefighter to function in any combination of these environmental conditions, the system shall have the following capabilities:

- Temperature - The system shall be able to operate in environments ranging from -50°C (-58°F) to 815°C (1500°F). At all temperatures below 95°C (203°F) the incident radiant flux shall be 0.142 watts/cm^2 at exposure times attainable by exhausting the breathing gas supply at minimum oxygen consumption rates. At temperatures of 95°C (203°F) and above, the incident radiant flux and exposure times are shown in Table 3-1.

- Pressure - The system shall be able to operate at altitudes ranging from 305 m (1,000 ft) below to 2300 m (7550 ft) above sea level

- Relative Humidity - The system shall be able to operate in environments where the relative humidity ranges from 0 to 100% at the temperatures and pressures previously listed.

- Explosive Atmospheres - The system shall be able to operate in methane rich, gasoline vapor rich, and other potentially explosive environments without creating a source of ignition.

Resupply/Recharge - In many instances the firefighter is called upon to work at the fire ground for several hours. In cases such as these, it is not uncommon for a firefighter to re-enter the fire scene after a rest and a resupply of breathing gases. To accommodate such situations the following criteria are established:

- The system shall have on-site recharge capability

- Recharging at the fire ground shall be accomplished within two minutes

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

Don/Doff - The system will most likely be stored on the apparatus. To prevent delay in entering the structure and to further encourage use the following criterion is established:

- The system shall be capable of being donned unassisted in 30 seconds. Doffing shall take no longer than 5 seconds.

Maintainability -

- Normal maintenance of the system shall be kept to a minimum. It shall be limited to cleaning and the replacement of expendables. Replacement of expendables will be done by each firefighter, whereas repairs shall be done only by qualified persons (trained by the manufacturer) using parts designed for the apparatus.

Reliability -

- Aside from the normal maintenance required for cleaning and recharging, the system shall be capable of satisfying all performance requirements for a period of 3 years, at a busy metropolitan fire house without requiring repair.

Durability - In the interest of economy the firefighters equipment must have a reasonable service life.....one which considers both the storage and operating environments that the equipment will be subjected to. The storage environment may be that of a fire station, fire apparatus, or even the inside of an automobile. In these instances the equipment may be exposed to vehicle exhaust gases, vehicle maintenance fluids (e.g., battery acids, brake fluids, gasoline, etc.), fire station cleaning compounds, and even possibly to household cleaning and laundering agents. Any of these will take their toll on the service life of the equipment although by comparison to the degradation anticipated in an operating, or usage, environment it will be small. In the usage environment, which can be internal or external to the fireground, the equipment is exposed to the potentially degradatory effects of both the natural elements (e.g. sun and rain) and the by-products of the fire namely, heat, corrosive gases, flame, etc. Its anticipated that service life degradation will be most pronounced in the usage environment.

The total effect on service life must be considered, however, and for this reason the service seen at a busy metropolitan fire company is given as the basis for the following requirement:

4.2 SELF CONTAINED BREATHING SYSTEM (Contd)

- The system shall meet the requirements of this document for a service life of 15 years at a busy metropolitan fire house.

Recognizability -

- The system shall be provided with retroflective surfaces on the side of the backpack exposed to view to make it visible at distances up to 200 ft at night.

Compatibility - To assure the effectiveness of the entire firefighting ensemble it is necessary that all the component items function well together. To this end the following criterion is necessary:

- The system shall not interfere with the donning or doffing of the head/ear protection subsystem. It shall be compatible with the Communication and Lighting Systems, and be capable of being donned over the torso/limbs protection subsystem.

REFERENCES FOR SECTION 4.2

1. American National Standard - ANSI 287.1 - "Practice In Occupational and Educational Eye and Face Protection"

2. "A Firefighters Integrated Life Protection System," Phase I Report, Sept. 1974, Grumman Aerospace Corp.

3. "Minimum Protection Factors In Respiratory Protective Devices for Firefighters," W. Burgess, E. Clougherty et al, Am. Ind. Hyg. Assoc. Journal, Jan. 1977

4.3 LIGHTING SYSTEM

The firefighter requires a personalized light for possible use during entry to and exit from the fire scene, and during search and rescue operations. The system should be lightweight, compact and an unobtrusive so that it can be readily borne by the firefighter at all times.

4.3.1 Requirements

Performance Criteria

Illumination - The firefighter requires a good beam of light both for safety and for performing firefighting duties. During day or night the firefighter is called upon to enter a darkened structure and maneuver through dark hallways, staircases and rooms. For this a Lighting System is required to enable the individual to find his way and to carry out search and rescue operations. Based on these requirements the following criterion is established:

- The Lighting System at a 15 m (49 ft) distance shall be capable of illuminating a 4.5 m (14.9 ft) x 4.5 m (14.9 ft) area (with no other light source present) so that the firefighter, assuming 20-20 vision, can identify a black target placed in the beam of light on a gray back drop. The intervening atmosphere shall be assumed to be slightly smoky.

Duration - The duration of the firefighters Lighting System must be such as to provide enough time for the firefighter to do the job and escape safely if necessary. In severe situations, the firefighter is active as much as half an hour before taking a breather, and may be required to re-enter the fire several times before the job is done. To safely handle instances such as this, the following criterion is established:

- The Lighting System shall be capable of providing at least one-half hour of light at required intensity without need of recharge.

Operation - As the Lighting System will not be in use all the time it must be capable of being turned on and off while the firefighter is on duty. Thus the following criterion is required:

- The Lighting System shall include a switch of rugged design, which is operable by a firefighter when wearing the hand/wrist protection subsystem. It shall be capable of 100,000 on/off cycles of operation without failure and have both a "Locked On" and "Locked Off" position.

4.3 LIGHTING SYSTEM (Contd)

Comfort Criteria

Weight

- The total weight of the Lighting System (including lamp lens case and battery) shall be a maximum of 225 gm (0.5 pounds).

Size

- The Lighting System shall be of such size and shape to make it readily hand-pointable (at least the lamp and lens portion), capable of being placed on a flat surface without rolling, and as small as possible.
- The Lighting System shall be designed to be secured to the torso protection subsystem or the head protection subsystem. It shall be capable of being operated in the secured position.

Service/Other Criteria

Recharge - The term recharge has two different definitions. At the fire ground where it may be necessary for a firefighter to rapidly recharge the subsystem an energy pack replacement will be used. At the fire station where more time and equipment is available, recharge can be accomplished using a battery recharger. Thus, the Lighting System shall have the following characteristics:

- The Lighting Systems shall be capable of recharge at the fire ground through the simple replacement of the energy pack within 2 minutes time
- The Lighting System shall be capable of recharge at the fire station using a suitable charger driven by 120 VAC, 60 Hz power, or on the fire apparatus with nominal 12 VDC power, within a one hour period.

Maintainability

- Normal maintenance of the Lighting System shall be limited to: energy pack replacement, lamp or lens replacement, energy pack recharge, and cleaning.

Reliability -

- Aside from the normal maintenance required for cleaning, recharging, and bulb replacement, the Lighting System shall be capable of satisfying all requirements for a service period of 2 years at a busy metropolitan fire house without requiring repair.

4.3 LIGHTING SYSTEM (Contd)

- The lamp, a replacement item, shall have an average rated life of 500 hours. It shall be interchangeable with commonly available lamps.

Durability - In the interest of economy the firefighters equipment must have a reasonable service life..... one which considers both the storage and operating environments that the equipment will be subjected to. The storage environment may be that of a fire station, fire apparatus, or even the inside of an automobile. In these instances the equipment may be exposed to vehicle exhaust gases, vehicle maintenance fluids (e.g., battery acids, brake fluids, gasoline, etc.), fire station cleaning compounds, and even possibly to household cleaning and laundering agents. Any of these will take their toll on the service life of the equipment although by comparison to the degradation anticipated in an operating, or usage, environment it will be small. In the usage environment, which can be internal or external to the fireground, the equipment is exposed to the potentially degradatory effects of both the natural elements (e.g. sun and rain) and the by-products of the fire namely, heat, corrosive gases, flame, etc. Its anticipated that service life degradation will be most pronounced in the usage environment. The total effect on service life must be considered, however, and for this reason the service seen at a busy metropolitan fire company is given as the basis for the following requirement:

- The Lighting System shall be capable of performing as specified herein for a period of 5 years at a busy metropolitan firehouse.

Environmental Operating Requirements - The environment that the firefighter works in varies from day to day, and month to month. Depending upon the type of fire, how, when or where it is fought, the temperatures, pressures, humidity, etc., all vary.

To accommodate these different environmental conditions, the Lighting System shall have the following capabilities:

- Temperature - The Lighting System shall be capable of operating in environments ranging from -50°C (-58°F) to 815°C (1500°F). Temperatures of 815°C (1500°F) will last for 10 seconds only, whereas temperatures of 250°C (482°F) will last 5 minutes and 95°C (203°F) for 15 minutes
- Pressure - The Lighting System shall be capable of operating at altitudes ranging from 305 m (1000 feet) below to 2300 m (7550 feet) above sea level
- Relative Humidity - The Lighting System shall be capable of operating in environments where the relative humidity ranges from 0 to 100%

4.3 LIGHTING SYSTEM (Contd)

- Explosive Atmosphere - The Lighting System shall be capable of operating in methane rich, gasoline vapor rich, and other potentially explosive environments without creating a source of ignition.
- Shock - The Lighting System shall be capable of withstanding repeated 4m (13.1 ft) drops on to a concrete pavement without suffering any damage or decrease in performance. It shall be capable of withstanding a total of 150 such drops without any damage or degradation.

Water Penetration - Every firefighter faces falling water which may be encountered from an open sprinkler head, broken pipe, a nozzle stream bouncing off walls and ceilings, or from a driving rain. This water may be ice cold or it may be steaming hot. Under conditions such as these it is imperative that the Lighting System continue to function so that the firefighter can perform his duties unimpaired, and that the System remain unaffected. Thus, the following is required:

- The Lighting System shall be completely waterproof and capable of properly functioning during and after having been submerged in water either at 82° C (180° F) or at 1^{o}C (34^{o}F) for 5 minutes.

4.4 COMMUNICATIONS SYSTEM

This section covers the performance requirements for the Communications System that will be adapted to the Firefighters' Integrated Response Equipment System. The primary function of this system is to provide individual firefighters with the capability to establish high quality, reliable voice communications with the field command post and between each other under the adverse conditions normally encountered at a fire ground. An equally important secondary function is to provide the firefighter with safety features such as an audible emergency-locator warning system and hands-free operation of communications equipment. These secondary functions are important additions which can readily be included into present-day communications systems.

Basic system requirements are presented which define overall functional, operational, environmental, and human factors aspects of communications equipment capabilities. These system requirements are most effectively met by utilizing a self-contained design using electronic miniaturization techniques commensurate with existing and projected technology capabilities.

Background

Effective fire fighting operations, as well as the safety of fire fighting personnel, depend to large measure on communications between members of a fire fighting team.

At the same time, there are a variety of conditions at the scene of a fire that limit the usefulness of certain communications media and complicate communication requirements. These conditions include (a) noise caused by the fire, by fire fighting apparatus, and by the crowd (b) restricted visibility due to smoke, (c) physical barriers to communications between firemen inside the burning structure and those on the outside, and (d) the large number of persons potentially involved in the communications network.

The development of an appropriate light weight, hands-off system, capable of effective functioning under such conditions, would be extremely helpful in improving fire fighting effectiveness and the safety of fire fighting personnel.

4.4.1 Requirements

Operating Modes

The Communications System shall be capable of operation in the following modes:

a) Voice, Push-to-talk (PTT) - PTT capability shall be available which provides conventional simplex voice operation controlled by a momentary-actuate switch.

4.4 COMMUNICATIONS SYSTEM (Contd)

When this switch is depressed the transmitter shall operate allowing voice transmission, and when released the receiver shall be connected for reception of incoming signals.

b) Voice, Automatic-Key - An optional Voice-operated-transmission (VOX) shall be made available and selectable by a momentary-actuate switch. When this mode is selected, VOX circuitry shall recognize the presence of a voice signal from the microphone and automatically key the transmitter as if PTT operation were being utilized. If no voice signal is present for a period of 20 seconds between transmission, the VOX mode shall automatically terminate and revert to the PTT mode. Momentary actuation of either the PTT or VOX switch shall also cause the VOX mode to terminate.

c) Sidetone - This mode shall automatically be established when in either the PTT or VOX mode of operation, and acts as a positive verification that user voice transmission is taking place by the presence of the users voice in his own earpiece. Since sidetone provides indication that the VOX mode is in operation, suitable action can therefore be taken should the user be unaware of this fact.

d) High/Normal Power - The High Power mode shall be selectable by momentary switch action and can be used in adverse signal propagation conditions where excessive RF signal dropout is experienced. This mode shall automatically revert to the Normal Power mode after 30 seconds to avoid inadvertent overtaxing the equipment power supply.

e) Emergency Warning Tone - This mode shall be selectable by user switch action and provides an audible signal indication of the user's location.

f) Remote-Active Functions - Continuing studies will determine the applicability of remotely activating (via RF command) such features as VOX, and High/Normal Power operating modes. Inclusion of a low data-rate command link to selectively operate these functions can provide invaluable safety features to an incapacitated user.

Communications Range - When using the Normal Power output mode, the equipment shall perform satisfactorily to line-of-site (LOS) ranges to 8 km (5 miles), and shall also be capable of reliable performance within a ten story steel/concrete building structure. When unusually complex physical barriers cause excessive signal attenuation, use of the High Power mode shall restore reliable communications.

4.4 COMMUNICATIONS SYSTEM (Contd)

The equipment shall perform satisfactorily in the Normal Power output mode to minimum ranges of 0.6m (2 ft) between users.

Communications Coverage - Communications coverage shall be omni-directional. The antenna shall provide omni-directional coverage at a minimum gain level of -3dbi gain above isotropic for greater than 95% of the upper hemisphere, and 10dbi for greater than 95% of the total sphere of coverage. This coverage shall apply for the entire frequency band of operation.

Communications Quality - Signal margin/antenna coverage shall be sufficient to provide 95% probability of intelligible reception of any 5 second voice message transmission.

Frequency Band - The equipment design shall be capable of operation within standard FCC approved channels in the VFH (150-170 MHz) or UHF (450-512 MHz) band. The choice between UHF and VHF shall be determined by controlled building-penetration RF tests in conjunction with antenna design considerations. Preliminary investigations indicate that neither band has significant building-penetration advantages. However, a UHF antenna may be smaller and easier to build than a VHF antenna.

Channelization - The equipment shall be operable in up to six switch-selectable channels as controlled by either crystal or frequency synthesizer. The specific number of channels to be provided is a function of the individual departments needs.

Environmental Requirements - The equipment shall meet operating and survival (powered) environmental requirements as follows:

- Temperature - -50°C (-59°F) to 250°C (482°F) (Operate)
- Humidity - 100% (operate)
- Immersion - 5 minutes in 82°C (180°F) and 1°C (34°F) water (survival)
- Shock and Vibration - 12 foot drop to concrete sidewalk (survival)

Physical Characteristics - Equipment shall be light-weight and of modular design to facilitate maintenance. When assembled in the head/ear protection subsystem, there shall be no mechanical interference with this subsystem. Maximum combined weight of all components including power supply shall be 454 gm (1.0 lb.)

All components shall be physically shielded from contaminants and external environment. No external connections (e.g. power, PTT switch, etc) shall be required to operate equipment.

4.4 COMMUNICATIONS SYSTEM (Contd)

A dynamically-balanced configuration of equipment shall be used which provides acceptable C.G./moment of inertial properties, and does not cause user fatigue or discomfort.

Power Source - Equipment shall operate from a self-contained rechargeable or disposable battery supply capable of 12 hours of operation. For the Normal Power output mode, a 10% transmit, 10% receive, 80% standby duty cycle is assumed. For the High Power output mode, a 5% transmit, 10% receiver, 85% standby duty cycle is assumed.

A fully charged power source shall be capable of continuously operating the equipment for the following time periods:

- Warning Tone Mode - 4 hr
- Warning Tone and Transmitter - 2 hr

Controls - Mode controls shall be easily accessible and operable by a firefighter wearing gloves. Controls shall be provided for the following functions:

- Transceiver on/off
- Volume
- VOX on/off
- PTT
- High/Normal Power
- Warning Tone
- Squelch
- Channel Select (as needed)

Equipment Status Indicators - Equipment status indicators shall be provided for the following:

- Transceiver on
- High Power on
- Power Supply low

Auxiliary Connectors - Auxiliary connectors shall be provided for the following external functions:

- External speaker
- External power source

4.4 COMMUNICATIONS SYSTEM (Contd)

Safety Provisions - The equipment shall meet the following safety requirements:

- Radiated field intensity from the antenna shall meet personnel safety hazard requirements of USAS C95.1.
- External controls and component protrusions shall be designed and located such as to preclude personnel injury should the communications system be jarred loose or be subjected to impact.

4.5 PERSONAL COOLING SYSTEM

Working in a normally hot environment, encumbered by his heavy, bulky protective gear, the firefighter is prone to suffer much discomfort and fatigue due to heat. To reduce firefighter's discomfort, and to prevent heat exhaustion, a personal cooling system is desirable. Studies conducted and/or sponsored by NASA Ames Research Center show that selective cooling of the head-neck area afford efficient thermal protection far beyond the relative amount of cooling used. It appears that head and neck cooling alone is sufficient for the firefighter. Thus for purposes of this standard, the Personal Cooling System shall be limited to head-neck cooling.

4.5.1 Requirements

Protection Criteria

Heat Protection - The fire scene thermal environment can be characterized by the four classes shown in Table 3-1. Previcus studies have shown that an individual can only sustain a heavy work rate (756 K cal/hr) for a period of approximately 30 minutes without becoming exhausted. Thus, a firefighter's cooling system should be capable of performance when the firefighter is working at this rate under the fire scene conditions described in Table 3-1.

Based on these considerations, the heat protection requirements for the Personal Cooling System are:

- Under Class 1, 2, or 3 conditions, the system shall be capable of maintaining the firefighter comfortably while he is working at an energy expenditure rate of 756 K cal/hr. for the conditions specified.
- Under class 4 conditions, the system shall be capable of maintaining its inner surface temperature below the Figure 3-1 temperature-time allowables.

Performance Criteria

Hearing - Because of the firefighter's need for communications

- No portion of the system shall inhibit hearing either by virtue of the noise it makes during operation or by the way it must be worn.

Comfort Criteria

Weight

- The weight of the Personal Cooling System shall be a maximum of five pounds.

4.5 PERSONAL COOLING SYSTEM (Contd)

Size and Volume

- The Personal Cooling System shall be hip or back mounted and be no more than 30 cm (11.8 in.) wide by 13 cm (5.1 in.) high by 7 cm (2.8 in.) deep. This size insures that the pack is within the firefighter's frontal profile and that the individual's center gravity is not significantly affected.

Fit

- The Personal Cooling System shall be capable of being worn by a firefighter equipped both with a head/ear protection subsystem and a torso/limbs protection subsystem. The headpiece shall be held in place by adjustable straps or an adjustable hood. Fit should be snug but not tight. The hip or backpack portion of the system shall be held in place by adjustable straps. Movement of the system shall be minimized during firefighting activities.

Water Penetration - The firefighter and his Personal Cooling System must remain unaffected by water. The following criterion is required:

- When donned, the system shall not absorb water nor shall water be allowed to enter any component when subjected to 82°C (180°F) water falling on it at a rate of 60 l/m (15.9 gallons per minute), from a sprinkler head from a height of 3 m (9.8 ft), for 10 minutes.

Service/Other Criteria

Environmental Operating Requirements - The firefighter works in various environments. Depending upon the type of fire he/she is fighting, how, where, and when he/she is fighting it, the temperatures, pressures, humidity, all vary.

To accommodate these different environmental conditions so that the firefighter can function in any combination the system should have the following capabilities:

- Temperature - The Personal Cooling System shall be capable of operating in environments ranging from -50°C (-58°F) to 815°C (1500°F). At all temperatures below 95°C (203°F) the incident radiant flux shall be considered to be 0.142 watts/cm^2. At temperatures of 95°C (203°F) and above, the incident radiant flux and exposure times are shown in Table 3-1.
- Pressure - The Personal Cooling System shall be capable of operating at altitudes ranging from 305 m (1,000 ft) below to 2300 m (7550 ft) above sea level.

4.5 PERSONAL COOLING SYSTEM (Contd)

- Relative Humidity - The Personal Cooling System shall be capable of operating in environments where the relative humidity ranges from 0 to 100% at the temperature and pressures previously indicated.
- Explosive Atmospheres - The Personal Cooling System shall be capable of operating in methane rich, gasoline vapor rich, and other potentially explosive environments without causing an explosion.

Resupply/Recharge - In many instances the firefighter is called upon to work at the fire ground for several hours. In cases such as these it is not uncommon for a firefighter to reenter the structure involved after a rest. To accommodate such situations, the following criteria are established:

- The Personal Cooling System shall have on site recharge capability
- Recharging at the fire ground shall be accomplished within 2 minutes
- Recharge shall be limited to the replacement of items such as batteries and spent cannisters containing the expendables.

Don/Doff - The Personal Cooling System will most likely be stored on the apparatus. To prevent delay in entering the structure and to further encourage its use, the following criterion is required:

- The Personal Cooling System shall be capable of being donned unassisted in 30 seconds. Doffing shall take no longer than 5 seconds.

Maintainability

- Normal maintenance of the Personal Cooling System shall be kept to a minimum. It shall be limited to cleaning and the replacement of expendables. Replacement of expendables will be done by each firefighter whereas repairs shall be done only by qualified persons (trained by the manufacturer) using parts designed for the equipment.

Reliability

- Aside from the normal maintenance required for cleaning and recharging, the Personal Cooling System shall be capable of satisfying all performance requirements for a period of 3 years at a busy metropolitan firehouse, without requiring repair.

4.5 PERSONAL COOLING SYSTEM (Contd)

Durability

- The system shall meet the requirements of this document for a service life of 15 years at a busy metropolitan firehouse.

Compatibility

To assure the effectiveness of the entire firefighting ensemble it is necessary that all the component items function well together. To this end, the following criteria are necessary:

- The Personal Cooling System shall not interfere with the donning or doffing of the head/ear protection subsystem. It shall be compatible with the Communication System, and be capable of being donned over the torso/limbs protection subsystem.
- The Personal Cooling System shall be compatible with the Self Contained Breathing Gas System. The headpiece shall not interfere with the donning or doffing of the Breathing System facepiece while the cooling pack shall not interfere with the breathing pack. This shall not preclude the possibility of both systems being integrated but separable units.
- The Personal Cooling System shall not interfere with the operation, deployment or storage of commonly used tools.

Section 5

GLOSSARY

ACCEPTANCE	Similar to currently used configurations
*"ALL HANDS"	A working fire at which all units of the first alarm assignment are actively engaged in fire fighting. An "ALL HANDS" is frequently followed by a multiple alarm or at least by the transfer of companies to cover the vacated territory
APPARATUS	A motor driven fire truck or a collective group of such truck types
APPEARANCE	The way it looks
AXIOMATIC	Self evident
*BACKDRAFT	An explosion or rapid burning of gases
"BLOW"	Jargon for rest
*BLOWUP	Sudden major increase in fire intensity, and rate of spread of a wildland fire often accompanied by violent convection and fire storm characteristics
BRAND	A piece of charred or burning wood
BTU	British Thermal Unit. The amount of heat required to raise the temperature of 1 lb of water $1^{o}F$
BUSY METROPOLITAN FIRE COMPANY	A fire company at which each man responds to approximately 700 alarms per year
CENTRIFUGAL	Away from the center
COMFORT	Minimum weight and encumberance
COMPATIBILITY	Function together
*CONDUCTION	Transmission through a conductor

*Fire Department Terminology - Fourth Edition, National Fire Protection Association (1970)

*CONVECTION	Heat transfer by a circulating medium either gas or liquid, as air heated by conduction circulates and transfers heat to distant objects in the room
CUT	Scrape or lesion (break in skin or material)
DEXTERITY	Ability to make fine adjustment (e.g., finger movement)
DOFFING	Remove
DONNING	Put on
DRYABILITY	Ability to be dried
DURABILITY	Service life
*EXTINGUISHMENT	To reduce flame and heat so as to prevent danger of further extension of fire, to bring a fire to the overhauling stage
FIRE GROUND	The operational area at a fire at which the ranking fire officer is in charge of all operations and at which firefighting is underway and at which fire fighting apparatus is standing by.
FIT	Measured to individual size
*FLASHOVER	Stage of fire when room or other area becomes heated to the point when flames flash over the entire surface of area
FLUX	A measurement of radiant heat
FROSTBITE	When tissue has been destroyed by low temperature
GRIP	Ability to grasp and hold a specific item
HYPOXIA	Deficiency in available oxygen
IMPACT	Come in contact with
INTERFACE	Contact or connecting point
INTERFERENCE	Affecting operation or function
*KNOCK-DOWN	To reduce flame and heat so as to prevent danger of further extension of fire, to bring a fire to the overhauling stage
LUMENS	Unit of light measure

*Fire Department Terminology - Fourth Edition, National Fire Protection Association (1970)

MAINTENANCE	Return to service
Ma/VOLT AC	Milliamps/volts alternating current - units of electrical measure
MOBILITY	Ability to move
*OVERHAULING	A late stage of the fire extinguishment process during which the area involved in the fire and the contents involved are carefully scrutinized for any remaining trace of fire or embers and during which process effort is made to protect property against further damage due to the elements, etc.
PAIN THRESHOLD	Point at which body experiences discomfort
PENETRATION	Puncture hole or cause to break
PUNCTURE	To penetrate or cause a hole or break
RADIATION	Heat transfer by radiant energy waves in forms transmitting or producing heat
RECHARGE	Refill or replace expendables; regenerate batteries
RECOGNIZABILITY	Identifiable and visible
RELIABILITY	Good performance with each use
*RESCUE	The saving of a life endangered by fire or accident generally employed in the sense of assistance to persons unable to help themselves although loosely used to describe assistance rendered to persons in danger or trouble
RETROREFLECTIVE	Material that reflects with light
SHARD	Broken piece or fragment
STREET CLOTHES	The minimal covering on a persons body consisting of a standard set of underwear, sport shirt and slacks, socks and low cut shoes.
SUBSYSTEM	Component/element of a system
SYSTEM	Consists of one or more subsystems

*Fire Department Terminology - Fourth Edition, National Fire Protection Association (1970)

TORSO	Body structure consists of trunk, legs, arms and neck
WINDCHILL	Expression for the cooling effect of wind

Section 6

ACRONYMS

ANSI	American National Standards Institute
FIRES	Firefighters' Integrated Response Equipment System
PEPS	Protective Ensemble Performance Standards

ABBREVIATIONS

A. C.	=	Alternating Current
PEPS	=	Protective Ensemble Performance Standard
PSI	=	Pounds Per Square Inch
PTT	=	Push to Talk
SCBS	=	Self Contained Breathing System
TDE	=	Technology Demonstration Ensemble
URC	=	User Requirement Committee
VOX	=	Voice Operated Transmission

Section 7

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